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Sleep-Induced Tinnitus Modulation-A Longitudinal Case Report Study

Rodolphe de Maistre*

ABSTRACT

Tinnitus perception can be modulated by numerous external and internal factors. Among internal factors, some patients report that sleep can induce changes in their tinnitus intensity. In the present study, we analyze a patient's sleep-induced tinnitus modulations by measuring on 59 consecutive days the night sleep duration, deep and light sleep phases, and the next day tinnitus loudness sensation. We observe a negative correlation between the light sleep phase duration and next day average tinnitus loudness. For this patient, total sleep duration of more than 8 hours in average is consistent with a lower tinnitus loudness sensation and improves the quality of life. These observations call for more studies on the light sleep phase, Rapid Eye Movement sleep and a possible relation with next day tinnitus loudness sensations on patients with sleep-induced tinnitus modulations.

Keywords: Sleep, Tinnitus, Sleep-induced tinnitus modulations.

Presedent of Agence Internationale De La Confiance Biologique, IMT Nord Europe Institute, Douai, France

***Send correspondence to**
Rodolphe de Maistre
Presedent of Agence Internationale De La Confiance Biologique, IMT Nord Europe Institute, Douai, France, E-mail: rdemaistre@protonmail.com

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INTRODUCTION

Tinnitus is a symptom defined as the conscious awareness of a sound for which there is no identifiable corresponding external acoustic source. The sound is heard only by the patient, nobody else can hear it. Subjective tinnitus has different forms and degrees of severity. This debilitating chronic symptom affects approximately 14% of adults, 2% experiencing a severe form of it[1]. The cause and mechanism of tinnitus is unknown up to now.

Here is a short analysis of the relations between tinnitus and sleep characteristics in a patient reporting sleep-induced tinnitus modulation.

The idea of these measurements follows on from Robin Guillard's research into sleep-induced tinnitus modulations[2], and from a patient who reported having in general a higher tinnitus loudness every Monday compared with other days of the week **(Figure 1)**, and a shorter sleep duration every Sunday night (because of his late sleeping time on Sunday nights and the need for an early start on Monday mornings Note 1).

DESCRIPTION OF THE SYMPTOMS OF THE PATIENT

The patient presented a bilateral tinnitus with sleep-induced modulation in both ears. The tinnitus onset was 20 months before the beginning of the observations for this study. The patient was a male, aged 54, and presented a normal audiogram with max hearing threshold between 30dB HL and 15dB HL[3].

At the time of the observations, the patient tinnitus predominance frequency was 8000 Hz, octave band 0.0018, and varied between 6 000 and 10 000 Hz (assessment made on the Diapason website https://fr.diapason-app.com/)[1].

No cause of this tinnitus could be clinically identified.

The patient was under medication: Mianserin hydrochloride 10mg every night prescribed for tinnitus related insomnia.

METHODS

For a period of 18 months, the patient recorded every day the Subjective Tinnitus Loudness (STL) on a scale from 0 to 100. At 0 there is no tinnitus sound, at 100 there is a very loud tinnitus sound sensation.

During the STL recording period, the patient's night sleep duration in hours and minutes was recorded every day for two months **(Figure 2)**.

The measurement of the sleep duration and the recording of the tinnitus loudness were done independently.

After the two months sleep duration recording we reconciled for each night's sleep duration the next day tinnitus loudness STL, to check if there was any correlation between the tinnitus loudness and the previous night sleep duration.

For the night sleep duration assessment, a WITHINGS STEEL HR watch was used by the patient, who wore it on his wrist. The Withings watch measures the duration of three phases of sleep: 1. Deep sleep phases, 2. Light sleep phases, 3. Awake. The awake time was not counted. We counted in hours and minutes the cumulative duration of the deep sleep phases (DSD Deep Sleep Duration), the light sleep phases (LSD Light Sleep Duration), and the Total Sleep Duration (TSD = DSD+LSD). The light sleep phases include the N1 and N2 sleep stages as well as the rapid eye movement phases (REM).

For the tinnitus loudness, the initial purpose was to record the STL every day for two years to evaluate its evolution and record data for possible future analysis. Due to the long-term purpose, an easy and consistent method of assessment needed to be used. The STL scale from 0 to 100 had 5 categories **(Table 1)**. At the end of each day, based on his loudness sensation over the whole day, the patient chose a STL value corresponding to the prevailing tinnitus loudness. The mode of evaluation is subjective, from 1 to 100 (at 0, there is no tinnitus), with categories, and comparative as the patient compared the tinnitus

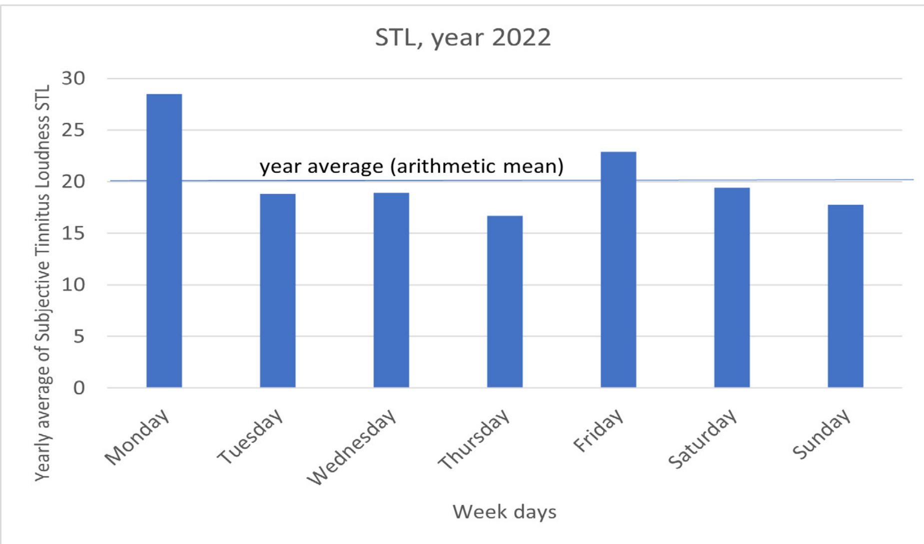

Figure 1: Arithmetic mean per weekday of Subjective Tinnitus Loudness in the year 2022.

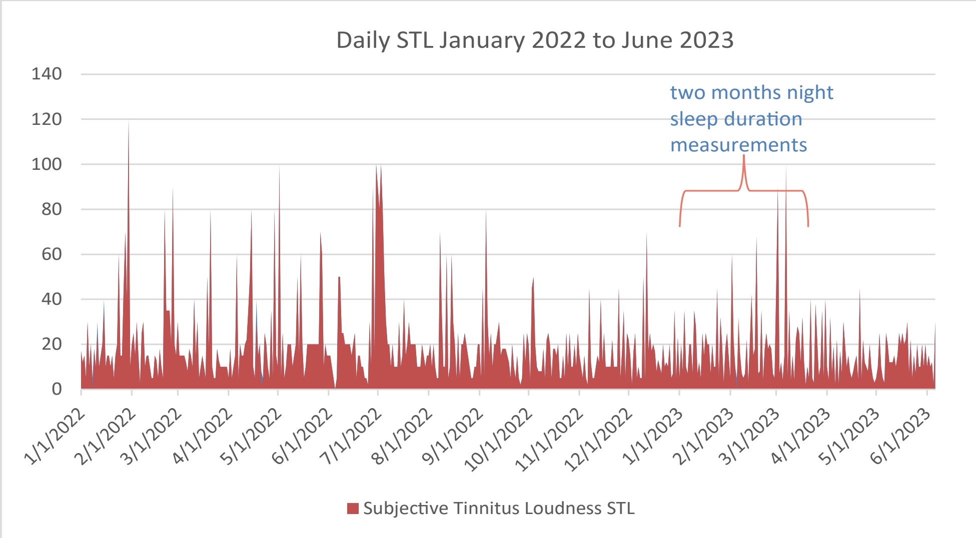

Figure 2: Two months sleep durations recording period over the total period of the daily Subjective Tinnitus Loudness recording.

Table 1: Subjective tinnitus loudness STL categories.

Tinnitus Loudness Categories	Mild	Medium	High	Severe	Acute
STL range	01-10	10-20	20-35	35-60	60-100
Type of similar sound from 6000 to 8000 Hz evaluated by the patient	small electric transformer, ticking watch	cricket field, an office room	fridge, a large business office	birds' song, squeaking door	electric saw, a site work with trucks and noisy machinery
Approximate typical sound level in dBA (for reference)	<35	35-45	45-55	55-65	65-85
Corresponding OSHA typical sound level (dBA) (for reference only)	20 - Silent study room	40 - Soft whispers (5 ft away)	50 - Urban residence	60 - Conversation (3ft away)	80 - Freight train (100 ft away)

loudness of the current day with the one of the previous day.

For reference, we indicated the typical sound levels in dBA as per US Occupational Safety and Health Administration OSHA[4]. For this reference, the approximate sound level in the STL category thresholds have been tested with tinnitus matching by the patient in dBA using a sound generator at the tinnitus equivalent frequencies. The sound generator was the website https://onlinetonegenerator.com/ connected to two speakers Panasonic SB-PM01 6Ω 30W each placed at 5 m from the patient and the sound level meter.

Following this procedure, the patient made a habit of measurement every day for more than a year. The measurements were therefore repetitive over a long time, made by the same operator, with the same method and with a constant time interval, which made them relatively stable.

RESULTS

We put on an Excel sheet all the TSD, DSD, LSD, and the next day tinnitus loudness volume STL. All 59 days' recordings were kept (no suppression of data).

Over 59 days, the tinnitus STL arithmetic mean Note 2) was M=20.4, the geometric mean G.M=14.3, and the range was between STLmin=3 and STLmax=100. STL was never at 0, i.e., the patient constantly heard his tinnitus with variable loudness and variable spectral characteristics. The average total sleep duration was M=8h03mn. A 2016 study provides an average loudness of tinnitus over a large population of 17dB[5], and a 2022 study provides an average sleep duration of a healthy adult of 7h **(Figure 3)**[6].

We want to check the correlation between the sleep durations and the STL.

The Pearson correlation coefficient measures linear correlation between two sets of data. For this correlation to be valid, the data must follow a normal distribution, which is not the case for either the sleep durations or the STL, and they must also be equal intervals of measurement, which is not the case for the STL.

The Spearman correlation is a nonparametric measure of rank correlation and assesses monotonic relation between two variables. It is based on ranks of the data and does not rely on linearity nor on normality of the data. Given that the data are not normally distributed, and that we want to check STL variation with sleep duration, the Spearman correlation coefficient ρ is appropriate.

Sample size: N=59

STL and TSD $\rho(57) = -.47$, $p = .00002 < .01$

STL and DSD $\rho(57) = -.20$, $p = .14$

STL and LSD $\rho(57) = -.52$, $p = .00003 < .01$

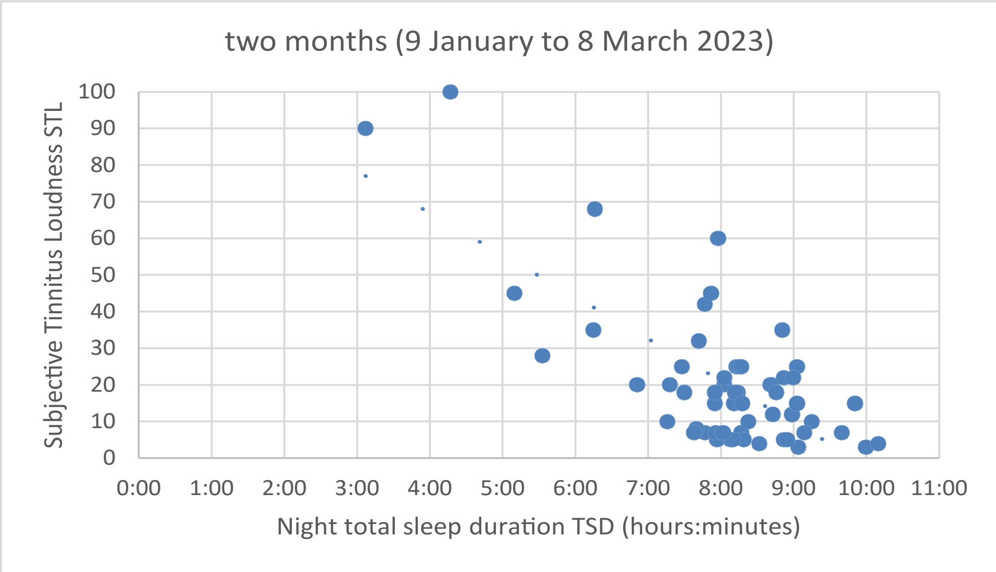

Figure 3: Night steep duration (total) versus next day tinnitus perceived loudness on 59 consecutive days (two months).

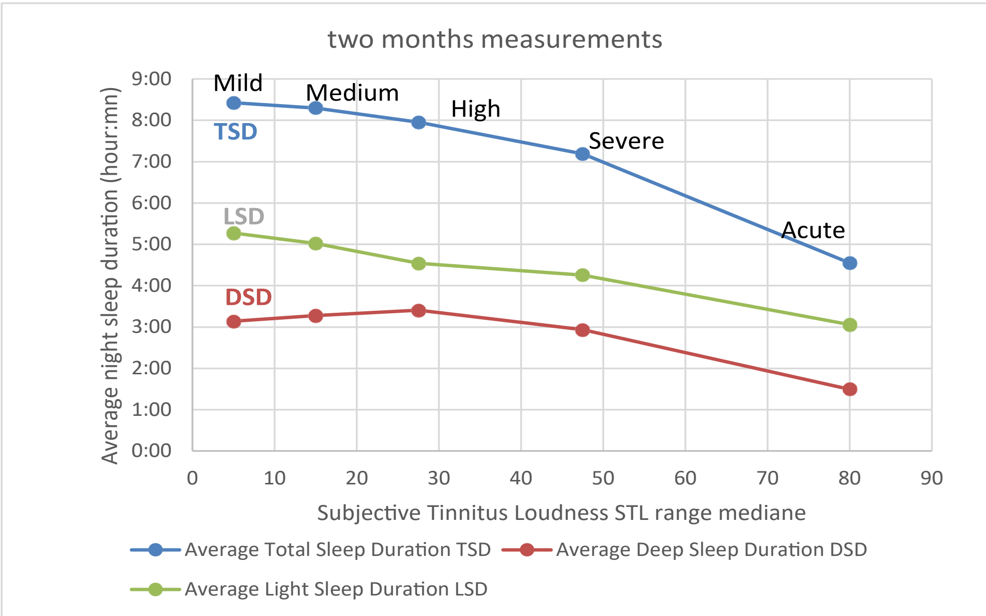

Figure 4: Average sleep durations (TSD, DSD and LSD) versus mid-ranges of Subjective Tinnitus Loudness STL during 59 consecutive days.

The Spearman correlation coefficients indicate a negative monotonic relationship between STL and LSD, and more moderately between STL and TSD. It doesn't indicate a monotonic correlation between STL and Deep Sleep Duration.

The WITHING STEEL HR also provides a Sleep Quality Score in percentages. The score is based on sleep duration, balance between deep and light sleep, sleep interruptions, regularity of the sleeping time, falling asleep and waking up durations. We checked the Spearman correlation of the STL and the Sleep Quality Scores:

STL and Sleep Quality Score $\rho(57) = -.30$, $p = .02$

To have a comprehensive chart, for each category of STL ranges **(Table 1)**, we calculated the average of the sleep phases' durations and obtained the following **(Figure 4)**.

DISCUSSION

In the present longitudinal study of the patient's sleep duration and subjective tinnitus loudness STL during two months, we identified that the patient had a negative correlation between Total Sleep Duration LSD and the Subjective Tinnitus Loudness STL ($\rho(57) = -.47$, $p < .01$); and also between Light Sleep Duration LSD and Subjective Tinnitus Loudness STL ($\rho(57) = -.52$, $p < .01$). No significant correlation between the Deep Sleep Duration DSD and the STL could be observed.

Longer the sleep duration, lower the average tinnitus intensity appears the following day. And longer the light sleep duration, lower the average tinnitus appears the following day.

The patient cannot control the split between deep and light sleep. However, the patient can control the overall

Table 2: Patient audiogram and tinnitus frequency.

Date	18-10-2021	13-12-2021	19-02-2022	22-02-2022	28-06-2022	22-08-2024
Ear side	Right	Right	Right	Right	Right	Right
Max hearing threshold a)	20 dB	30 dB	20 dB	30 dB	15 dB	15 dB
Max hearing threshold frequency b)	6 000 Hz	6 000 Hz	6 000 Hz	6 000 Hz	2 000 Hz	8 000 Hz
Subjective Tinnitus Loudness STL	60	30	10	35	35	25
Tinnitus frequency c)	6 000 Hz	6 000 Hz	6 000 Hz	6 000 Hz	8 000 Hz	11 500 Hz
Ear side	Left	Left	Left	Left	Left	Left
Max hearing threshold a)	25 dB	35 dB	35 dB	25 dB	20 dB	20 dB
Max hearing threshold frequency b)	6 000 Hz	6 000 Hz	6 000 Hz	750 Hz	1 000 Hz	6 000 Hz
Subjective Tinnitus Loudness STL	0	30	10	35	35	25
Tinnitus frequency c)	/	6 000 Hz	6 000 Hz	6 000 Hz	8 000 Hz	11 500 Hz

a) The hearing threshold is the sound level below which a person's ear is unable to detect any sound.

b) In the range 125 - 8 000 Hz

c) Tinnitus matching using Diapason website https://fr.diapason-app.com/

sleep duration by:

Not using any wake-up alarm, only natural wake up

Regular sleeping schedule

Medications Note 3)

For STL between 5 and 40, the average DSD does not vary, while average LSD and TSD have a linear negative correlation with the STL.

For STL higher than 40, both DSD and LSD decreases.

As it emerges from Figure 4, if the patient performs an adult standard time of 7h per night sleep, the average STL the next day would be severe (around STL 50 on the chart. In everyday life this loudness hearing sensation is very disturbing and causes a handicap to the patient).

At a STL under 20, the tinnitus is in the mild or medium range. With a STL in the ranges mild and medium, the patient reported that he can have a quasi-normal quality of life. For this patient, one solution to reach this quality of life is to sleep more than 8h per night, or, have a light sleep duration of more than 5h per night, both corresponding to a STL around or below 20.

8 hours sleep means a sleep duration 15% more than a standard 7 hours night sleep.

For tinnitus patients with similar symptoms, we recommend consulting a neurologist with sleep and tinnitus specialties to find the right method and medication to improve his/her tinnitus conditions.

CONCLUSION

On a patient with sleep induced tinnitus modulation, we observed a negative correlation between light sleep duration and tinnitus loudness level based on daily measurements over two months.

To have a better quality of life, this patient would have to sleep 15% more than a normal adult sleeping duration, i.e. more than 8h instead of a normal 7h per night.

The increase of the sleep duration above 8 hours results for this patient in a longer light sleep and a lower overnight tinnitus loudness sensation on average and has little impact on the deep sleep duration.

For patients with similar sleep-induced tinnitus modulation, we recommend consulting a neurologist specialized in sleep and tinnitus.

More studies should be done to explain the correlation between LSD and TSD, and to explore if the REM phase in the LSD is related with tinnitus and the mechanism behind it.

NOTES

Note 1: Evolution of the patient audiogram and tinnitus frequency

The evolution of hearing loss versus tinnitus frequency could be the object of another study: In our case study, it seems that the patient's hearing improved while the tinnitus frequency increased in time. See **(Table 2)** below.

Note 2: The average STL in the 2 months of the night sleep duration measurement are similar to the ones measured during 18 months: in one year and a half **(Figure 2)**, the STL M=20, G.M=15.

Note 3: After the night sleep duration measurement, the patient did a nocturnal monitoring polysomnography. The diagnosis of the polysomnography revealed sleep quality issues. As a treatment, in addition to Mianserin 10 mg per night, Clonazepam 2.5mg/ml 3 to 7 drops per night was prescribed, and it improved the patient's tinnitus conditions.

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SUPPLEMENTARY

1. Incorporation of the uncertainty in STL

Care needs to be taken in interpreting STL due to the fact that the measures were subjective and could depend on the psychological state of the patient. Also, the comparison could be difficult when the tinnitus loudness increases (or decreases) by small values several days in a row and thus could induce a shift. So the STL values have an uncertainty combining a random error due to subjectivity and psychological state of the patient, and a systematic error due to difficult comparison.

To evaluate the uncertainty of the STL, we have taken the STL values over 1.5 years, and checked the variations from one day to the next day. Over a large number of measurements, the random error is less relevant than systematic error, so we considered the systematic error only. We eliminated the variations higher than 50% and lower than -50% because it meant a sharp increase and respectively a sharp decrease where the systematic error is not relevant. For variations below 50% and higher than -50%, we find an average of +27% / -28% daily variation. To be conservative, we considered the uncertainty of the STL at +/-20%.

We can model each STL with a range to account for its uncertainty. For such, we have replaced the STL by STL fuzzy = STL^x(1+ random number between [-1; 1] ^{x}20%). We have made 50 simulations with this method. The classification of the Spearman correlation coefficients found was:

STL fuzzy and TSD ρ(57)min= -.52, ρ(57)max= -.40, 32 times between -.47 and -.44, p<.01

STL fuzzy and LSD ρ(57)min= -.55, ρ(57)max= -.45, 38 times between -.52 and -.48, p<.01

In each simulation we find a negative correlation close to the one made on the observations, and in most of the simulations the results are very close to the one made on the observations. Thus, the negative correlation between STL and LSD is still valid with a +/-20% STL uncertainty.

2. Pearson Correlation

We could check the consistency of the negative correlation using Pearson correlation coefficient. For such, we transformed the distributions into normal distributions.

The STL has few high values that skew the distribution rightward (positive skew) **(Figure 5)**.

Applying a log transformation to the STL leads to a more balanced distribution. With log (STL), Shapiro-Wilk test statistic W = .969, p = .133. The p-value being greater than .05, we did not reject the null hypothesis and thus there is no evidence of non-normality of the log transformed STL. The Q-Q plot to a standard normal distribution lies approximately on the identity line and suggests that we can use a parametric method.

The sleep duration does not follow a normal distribution because of the sleep pattern of the patient. Sometimes the patient experiences insomnia resulting in very short sleep duration. His insomnia is followed by long sleep duration to recover from the lack of sleep **(Figure 6)**.

The Box-Cox transformation B with λ> 1 reduces the variance at the extremities. With visual examination of Q-Q plot to a standard normal distribution, we found that λ=3 is best to reach a normal distribution, as the plot lies approximately on the identity line. Log transformed STL is a Cox-Box transformation with λ=0.

We checked the correlation of STL and sleep durations with Pearson coefficient r applied on the transformed values B(x, λ) .

B(STL, 0) and B(TSD, 3) r(57)= -.58, p = .000002 <.01

B(STL, 0) and B(DSD, 3) r(57)= -.26, p = .049

B(STL, 0) and B(LSD, 3) r(57)= -.55, p = .000007 < .01

The Pearson correlation coefficients indicate a negative linear relationship between the transformed Total Sleep Duration, Light Sleep Duration and log-transformed STL. This is consistent with Spearman rank correlations results.

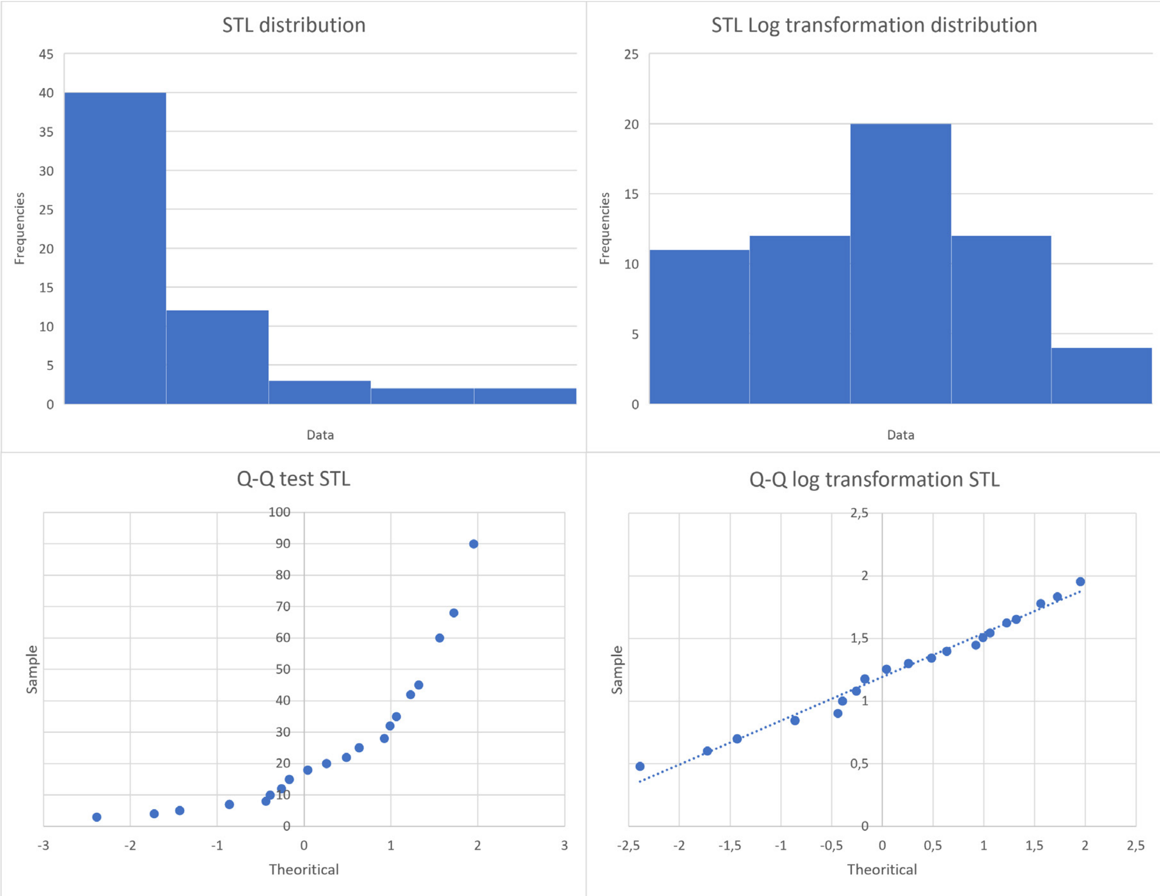

Figure 5: Subjective Tinnitus Loudness distribution and Q-Q test.

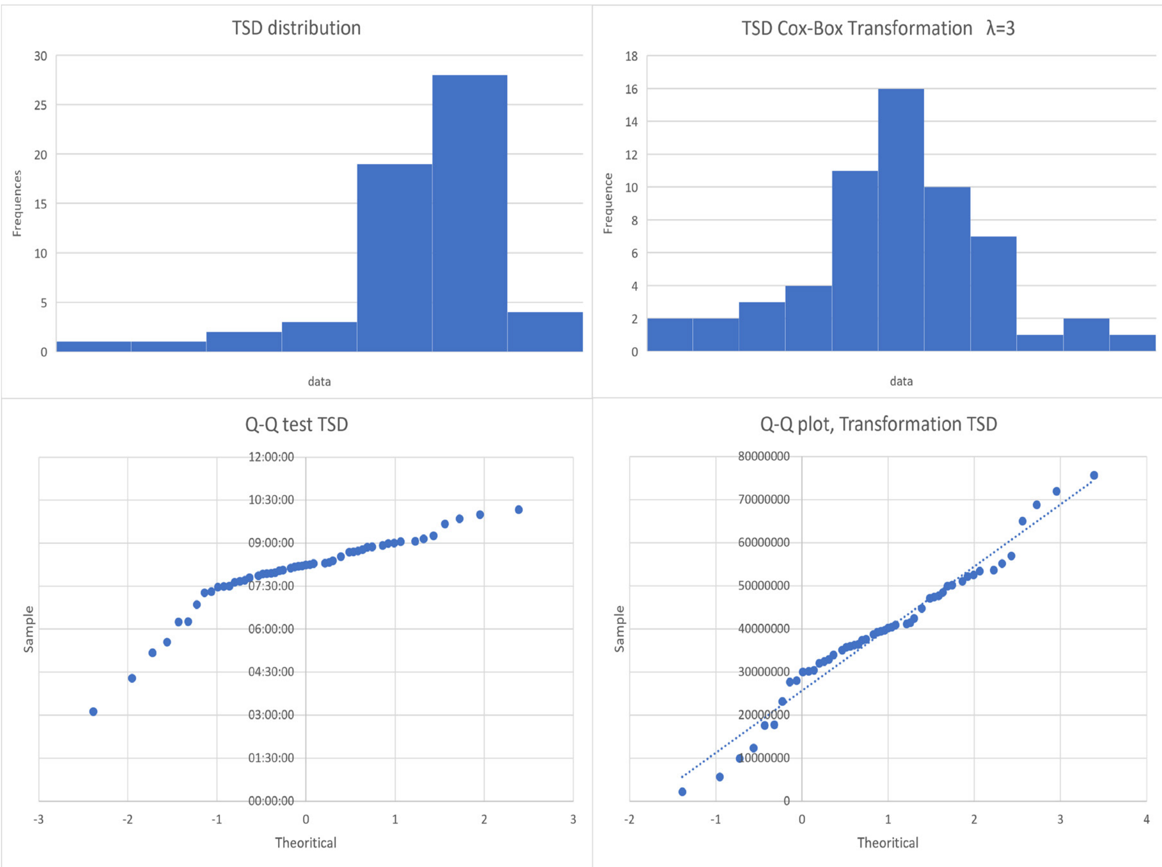

Figure 6: Total Sleep Duration distribution and Q-Q test.