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ANALYSIS OF VEHICLE INTERIOR NOISE CORRELATION TO ROAD TRAFFIC ACCIDENTS CAUSED BY DRIVER SLEEPINESS

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Abstract. *Sleep at the wheel is responsible for about 30% of road traffic deaths in the country, according to ABS (Brazilian Sleep Association). When correlating the cerebral behavior during stages of sleep initiation and acoustics in the vehicular environment, the present study raised the hypothesis that an induced sleepiness can occur by the noise inside the automobiles, being this one, triggered by pink noise soundwaves. In this context, this work aims to analyze aspects between sleepiness at the wheel and traffic accidents, the applicability of clinical pink noise for sleep induction and to compare it with the vehicle interior sound in order to classify it, or not, as a pink noise. Applying techniques of signal processing for the data acquired and after graphical comparison by spectrograms, it is concluded that the sound recorded inside the car evaluated during long road trips confirms its classification as pink noise.*

Keywords: Acoustics, Interior, Vehicle, Pink Noise, Sleep.

1. INTRODUCTION

In recent decades, osteoporotic fractures have been recognized as one of the most common causes of disability and one of the main contributors to increased health care expenditures, being associated with increased mortality, especially for vertebral and hip fractures (Shi, 2010). Whole body vibration (WBV) is an exercise that uses high frequency mechanical stimulation generated by a platform and transmitted through the body to the bones in order to stimulate the sensory receptors (Fratini, 2016). The negative effect of acidosis on the skeleton has been known for nearly a century.

According to ASIRT (International Road Safety Association) about 1.3 million people die in road accidents each year, an average of 3,287 deaths per day, and another 20-50 million are injured or disabled. In Brazil, sleepiness and fatigue represent 60% of the causes of road accidents according to ABRAMET (Brazilian Association of Traffic Medicine). Analyzing only sleep at the wheel, it accounts for 30% of deaths caused by road accidents in the country, as revealed by ABS (Brazilian Sleep Association).

The observation of some passengers behavior inside the cars during long distance trips revealed an interesting fact that awoke the motivation of the present work. Almost all children observed, and even some adults - occurs less frequently probably due to other mental occupations and even focus on keeping state of attention - just minutes after beginning the journey, felt completely asleep. The sleep state was apparently deep and prevailed for a long time. The curiosity was that whenever stops occurred, whether for fueling, feeding or for sanitary use, the tendency of these passengers was to immediate wake up in an alert state, even though what was happening to the noise levels inside the vehicle along the deceleration maneuver was the total reduction.

From this, the raised hypothesis suggests that the constant noise generated by the road and car components during long trips would be able to cancel, at a cerebral level, all the other sounds that could possibly trigger awakening, creating a certain kind of "virtual silence" that enables the sleep induction. The category of noise that presents this masking characteristic refers to signals of constant amplitude over the spectrum, which are referred as White noise, and as they are not pleasant to human audition, Pink Noise could be more related to that, as it preserves the masking potential while concentrating its higher amplitude sound levels at a low-frequency range. Technically, these sounds are able to mask all other noises in the environment that could disrupt or distract the individual, which promotes states of relaxation, and are even used in clinics for patients suffering from insomnia due to their sleep induction potential (Loewen, 2011). Popular natural examples would be: sea, rain, storm, crackling fire and strong wind. Current diary examples refers to static telephone noise, TV at inappropriate frequencies or low volumes, and even the fan (Mancini, 2009). This explains the common preference of people that must leave the ventilator or the TV in low volumes in order to fall asleep, a fact that culminated in the creation of the "sleep" function of the current electronic devices, being in some cases, indispensable for sleep initialization, what is observed especially on large cities inhabitants.

Residents of large urban centers tend to present poor sleep quality due to small and frequent nocturnal awakenings. Contrary to popular belief, what usually awakens people during the nights is not the high amplitude of the noise from the cities themselves, but their variability (such as when a noisy truck passes nearby), causing micro-awakenings, which prevent the REM sleep stage achievement (Kawada, 1993). In this sense, clinical noise aims to create a constant sound environment in order to eliminate any disturbance by other noises, as well as excite brain frequencies that allow the deep sleep stages stimulation (Scott, 1972). Sound variable environments effects on brain also could explain the immediate awakening of the passengers observed during vehicle stops. This could happen not because of loud noises, even because the tendency of the sound volume inside the car is to decrease with the reduction of speed and subsequent stop, but rather by the abrupt variation of the previously stable sound environment which had the noise ceased, activating the passengers brain immediately in a state of alert by a biological defense mechanism that, in most cases, is enough to wake them up.

Most people sleep with their eyes closed or at least in the penumbra, canceling the visual perception responsible for more than 90% of the information that humans receive. However, the hearing system - second largest sense relating to amount of information - keeps its channels open even during sleep, sweeping the surrounding space 360 degrees to detect any sign of danger (Souza, 2001). It is an evolutionary defense mechanism that characterizes and validates external noise as safe (quiet or constant noise environments) or not, being able to wake the brain immediately in case of probable threat; a situation that was of great importance for survival in the past due to potentially predatory animals.

Anund *et al.*, (2015) conducted a survey to investigate the effect of low-frequency automotive noise on driver sleepiness and performance, from which they conclude that: "The results support to some extent the hypothesis that road-induced vehicle internal noise affects performance. The increased low-frequency noise tends to reduce speed during daytime and nighttime driving, but also helps to increase the number of crossings at night. "

Many studies that correlate states of sleepiness and induced fatigue are found in the literature (Garder *et al.*, 1995; McCart *et al.* 1996; Nordbakke *et al.*, 2007; Sagberg, 1999) and their association as a major cause of severe traffic accidents (Arnold *et al.*, 1997; Fell, 1994; Horne, 1995; Maycock, 1997; Reyner, 2002; Sagberg, 1999; Summala, 1994; UK Department of Transport, 2002). However, none of them mention the fact that the acoustics promoted by the interior of automobiles could be creating a perfect environment for the sleep induction in drivers, which would then represent one of the main indirect causes of accidents. The literary review also found a complete lack of wresearch associating interior noise in automobiles during long trips with the category of pink/white noise.

Taking this point of view, the present article aims to reveal the dangers associated with drowsiness and traffic accidents, highlighting the effectiveness of using clinical constant noise for sleep induction and to compare this type of sound with road induced noise. For this, the noise inside a vehicle will be recorded during several long journeys, for different roads and at different speeds. The spectrogram of each wave will be presented graphically to allow a reliable comparison and the results analyzed judiciously.

2. LITERATURE REVIEW

A broad bibliographic review of the vibration techniques applied to osteoporosis treatments will be carried out in detail, mainly evaluating the methodology used in each research in order to verify the existence of associations of bone mineral density increase by WBV induction on volunteers. Subjects related to the mechanism of regulation of blood pH will also be evaluated in order to corroborate the relevance of the proposed objective.

According to data from CISA (Health and Alcohol Information Center) about 18% of accidents are caused by drunkenness, most of which involve fatalities. According to global statistics, around 15-30% of accidents are related to sleepiness at the wheel, representing an even greater risk factor than alcohol. Nevertheless, sleepy drivers cannot be detained at police stations, the ones who suffer from habitual sleepiness make up a special risk group and are as dangerous as those with illegal levels of blood alcohol (Haraldsson, 2011).

To evaluate the relationship between tiredness and drowsiness, Castro *et al.*, (2004) conducted a study on 238 bus drivers. The results showed that 45% reported having had or nearly suffered an accident while driving, 55% slept less

than 6 hours a day, 56% reported being tired at least part of the time while driving and 32% reported prolonged involuntary eye closure. The measures they usually take to avoid falling asleep while driving includes: wetting the face with water, eating fruit, opening the driver's compartment window, drinking coffee and listening to music. The study, yet, made no connection between sleep and noise inside buses, which produces a sound more related to pink noise, even more effective for sleep inducing (Kawada, 1993). This relation is similar to the findings of McCart *et al.*, (2000) who followed 593 truck drivers, of whom, 47.1% assumed they slept behind the wheel, without any association with the intense noise.

Regarding the influence of these sounds on the induction of sleep in newborns, the correlation is unanimous, perhaps due to the proven characterization of the uterus sound as white/pink noise (Planes *et al.*, 1984; Wolfs *et al.*, 1979; Larks, 1960). The study by Spencer *et al.* (1989), assessed two groups of newborns by submitting them to constant sound waves of 67 dB, revealing that 80% of the babies slept in less than 5 minutes using noise, compared to only 25% of the control group which fell asleep spontaneously. The use of white/pink noise for purposeful induction of sleep is frequent in the literature (Spencer, 1989; Eberhardt, 1987; Kawada, 1993; Anund, 2015).

In this context, patents have been developed since, according to WHO (World Health Organization) data, approximately 40% of the world population suffers from some type of insomnia. Rautiola (1968) has patented an acoustic sleep induction device consisting of a doll equipped to emit repeated sounds, coupled with a second pure emission component of a white noise. The doll format enhances the application for children and newborns, given the efficacy demonstrated in the aforementioned work by Spencer *et al.* (1989). Zentmeyer (1971), acquired a patent for the creation of a method and prototype capable of emitting modulated frequencies of audio signals for inducing sleep in humans. The volume level of the sound output must be adjusted to be sufficient to mask the ambient noise of the specific location, preventing intermittent and unwanted sounds from being heard consciously.

Williamson (1982) has patented a device for inducing brain wave patterns associated with states of relaxation and meditation from a pink noise source connected to a circuit to modulate its power spectral density.

Kawada *et al.*, (1993) studied the effects of 60dB continuous noise with pressure level control in order to keep it constant. This control makes this type of sound wave even more similar to the noise of buses and trucks than the common white noise, being characterized in the work as pink noise. The results showed that exposure to noise was associated with the shortening of sleep latency periods (elapsed time between lying in bed and the appearance of the first brain waves of the early stages of sleep), reducing the time by up to 9.5 minutes, representing a decrease of 58.7% compared to the mean time of the control group.

The correspondence between the types of white noise for sleep induction and the characteristics of the sound inside the car was observed in some previous studies (Eberhardt 1987; Anund, 2015), and even though they did not aim exactly what is proposed in this work, some important information was shown. Eberhardt (1987) studied the effects of road traffic noise on sleep in the laboratory. Intermittent noise averaging 45 dB delayed sleep initialization, whereas at 55 dB it was sufficient to awaken the subject. However, continuous noise did not present disturbances in the initial stages of sleep that maintained the same latency period. The study also found that the probability of awakening reactions caused by sounds depends on the emergence form of the noise peaks, not purely at their absolute levels. Anund *et al.* (2015) have shown that little is known about the influence that external factors such as road type, sound and vibrations have on the driver's ability to stay awake. Thus, although performed in a simulator, this study was one of the pioneers in the evaluation of the effect of low frequency noise, proving the sound influence of the road on patterns of sleep induction and worsening of the drivers performance by the increase of track crossings. Nevertheless, it was not even mentioned the possible characterization of this sound as pink noise, revealing unprecedented tone to what is proposed in the present work.

3. METHODOLOGY

To determine the clinical white noise to be used as the comparison basis, many sounds of meditation, relaxation and sleep induction used in insomnia treatment available on the internet were analyzed. When checking their spectrograms, a great similarity was verified, adopting, therefore, the criterion of choice on the greater number over the internet, what possibly indicates a greater effectiveness in the accomplishment of its objective.

The choice of the car started by the assumption that if in a luxury vehicle the intensity of the sound inside the car coming from the road is high enough to mask random intermittent noises, the same would be true for vehicles of lower categories since they tend to present worse levels sound insulation and increased noise from the road. Thus, a sedan type car was used for noise recording during trips in the state of Minas Gerais, comprising stretches between Tiradentes, Piumhi, Arcos, Divinópolis and Belo Horizonte. Tire pressure was calibrated at 30lb, as recommended by the vehicle manual.

The methodology used is in compliance with ISO 5128: 1980, which deals with the measurement of noise inside motor vehicles, using an electret type microphone (measurements made with closed glasses) model Mc40173 with frequency response of 50hz-16khz, low level of noise, omnidirectional and sensitivity -55 dB with an error of 2 dB. It was recorded in the position of the head of the front passenger, without any incidence of wind noise as both doors and windows remained closed, keeping also off the air conditioning. The installation prevented influences from the car's

vibration and was performed 0.3cm from the normal position of the passenger's head. The tests were still classified with the presence or not of rain and under a wide range of speed (from 60km/h to 180km/h), admitting variability of 20km/h. Which means that the graph corresponding to the speed of 100km/h ensures that the speed of the vehicle lies between 90-110km/h and so on. Speeds lower than 60km/h were not presented in the present study since the research is focused on noise induced by roads during long journeys and in stretches where the conduction can be carried out in a continuous way, which admit gradually higher speeds, excluding urban roads and traffic lights.

The data processing for audio comparison to validate or not its similarity was inspired by the algorithm of a software capable of revealing the name of a song from the recording of a stretch of only 15 seconds, even under environments of interference noises: the Shazam. The article published by Wang et al. (2003), one of the developers, details its functioning from time-frequency constellation analysis by combined crossing, creating pairs of frequency peaks and defined time intervals, which ensures the correspondence, regardless of the position of the recorded segment. Plotting the wave spectrogram is the first step and allows accurate comparison. Nonetheless it carries too much information for processing in such a short space of time, which would make it impossible to compare an audio segment with a bank of more than 2 million songs. Therefore, the program extracts the peaks of the spectrogram shown as an example in Figure 1, simplifying it by making it a constellation map. It creates the digital identity composed of bit sequences in hexadecimal base that maps and fixes variable length data in codes by Hash function, reducing the volume of information.

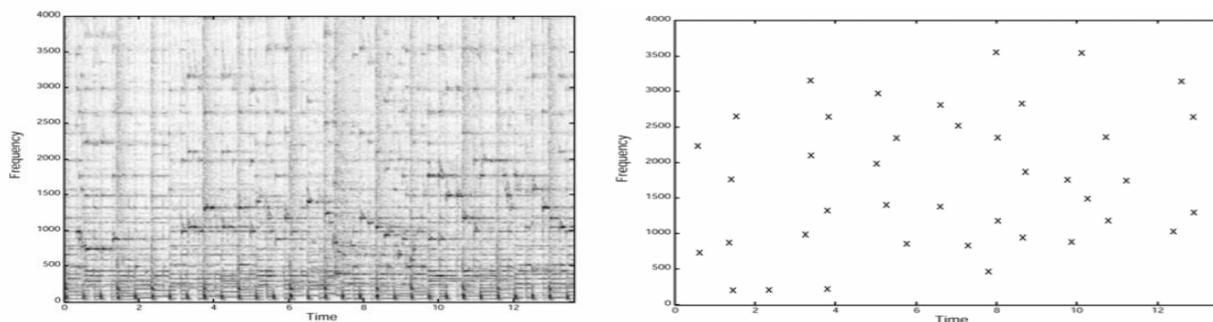


Figure 1. To the left, spectrogram and, to the right, constellation map. Fonte: Wang et al., 2003.

A careful analysis of the first stage of the algorithm function (spectrograms creation) is enough to enable the internal noise classification of the car, since time is not a limitation. In this way, the open license software Spek (version 0.82) and Audacity (version 2.1.2) were used to trace the recording spectrograms and clinical pink noise.

4. RESULTS AND DISCUSSION

Figure 2 shows the spectrogram of three pink noise induction sleep files available over the internet. The similarity in the distribution profile of the intensity of sounds is evidenced, emphasizing a higher concentration for low frequency levels, a characteristic that potentiates the induction of sleep. Because the leftmost file has been accessed the most times, subsequent comparisons are based on it.

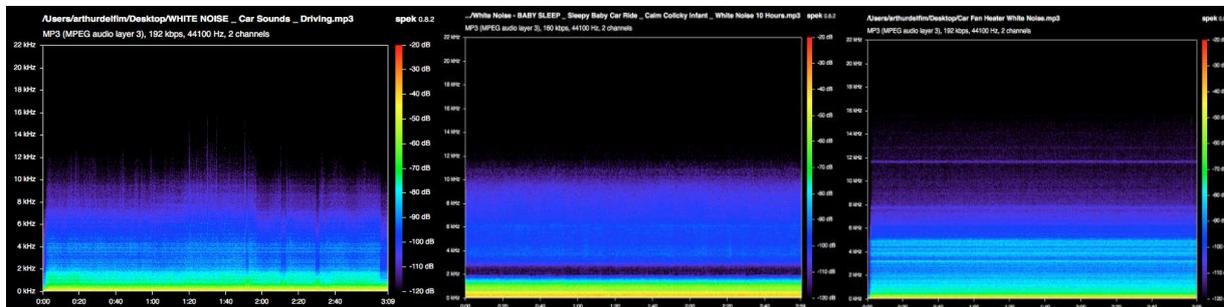


Figure 2. Three examples of pink noise audio files in the internet that are used to clinical sleep induction

Figure 3 reveals an extremely similar graphic pattern between the pink noise chosen to be the basis for comparison and the 10 minutes length sound recorded inside the car at a speed ranging from 80km/h to 100km/h on the MG-170 stretch from Arcos to Piumhi. A certain variation in the recording is observed around 4 minutes due to a fast speed overtaking that occurred from the 03:50 instant.

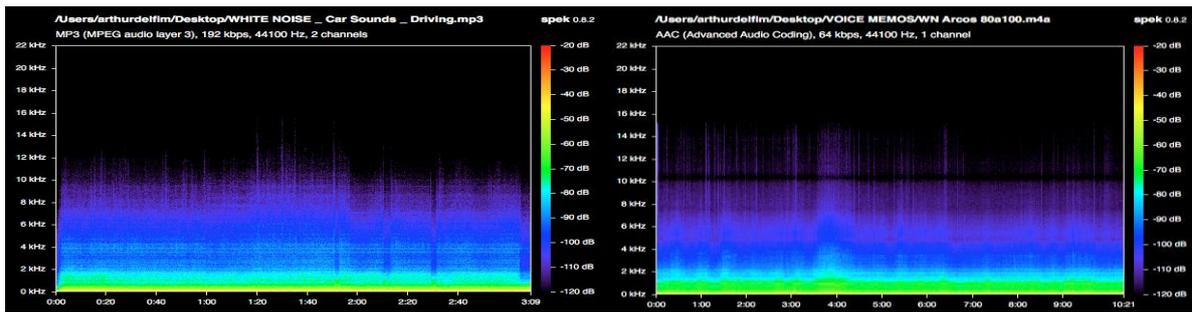


Figure 3. To the left, clinical pink noise and to the right, automobile recording at 80-100km/h without rain.

Figure 4 refers to the stretch of MG-050 between Formiga and Divinópolis at 140km/h, showing the same spectrogram profile. The difference with respect to Figure 3 is that the increase in speed would be related to sound amplitude rising at low frequencies, extending high intensity bands, shifting all the projection upwards.

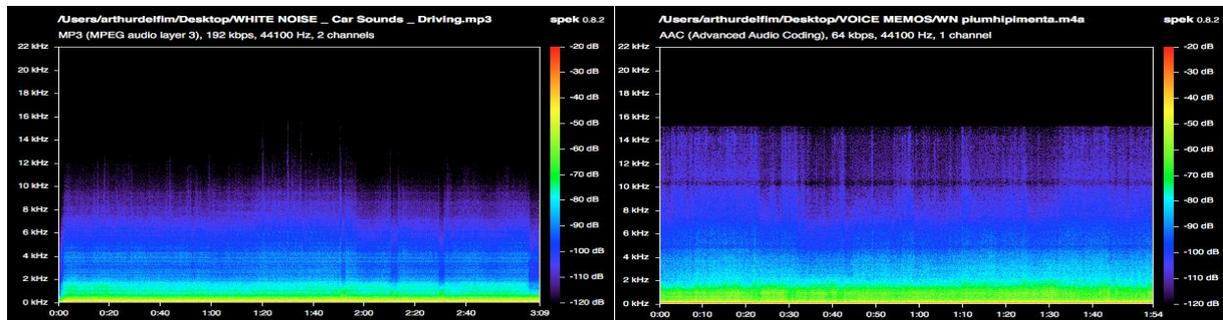


Figure 4. To the left, clinical pink noise and to the right, automobile recording at 140km/h without rain.

In order to clarify the displacement relation of the sound amplitude range, different velocity levels (100km/h and 180km/h) were kept in an increasing and interval way, as shown in Figure 5. Transitional moments were reported through descriptive speech for identification in the spectrograms, visualized as vertical bands of 80dB amplitude, highlighted in red for easy understanding.

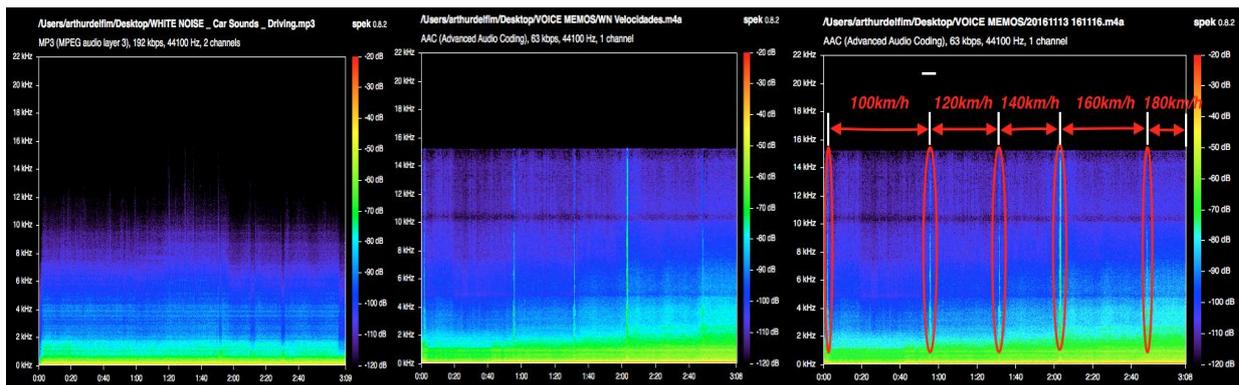


Figure 5. To the left, clinical pink noise, at the middle, automobile recording at rising speed intervals and to the right, transition speed moments identification.

A certain proportionality between the velocity and the amplitude of the waves at lower frequencies is observed, always maintaining the same spectral power density profile. The higher the velocity is, bigger would be the intense amplitude range starting from low frequency regions, creating a sort of upward shift of the colors on the graph, which represent the levels of sound intensity.

To increase the reliability of the aforementioned data, the same comparison was performed using Audacity software, which indicated the exact same pattern of noise correlation. The spectrogram and waveform for this same condition are shown in Figure 6, allowing a clear observation of the increase in wavelength due to speed increase and the similar profile of a clinical pink noise, even at higher speeds.

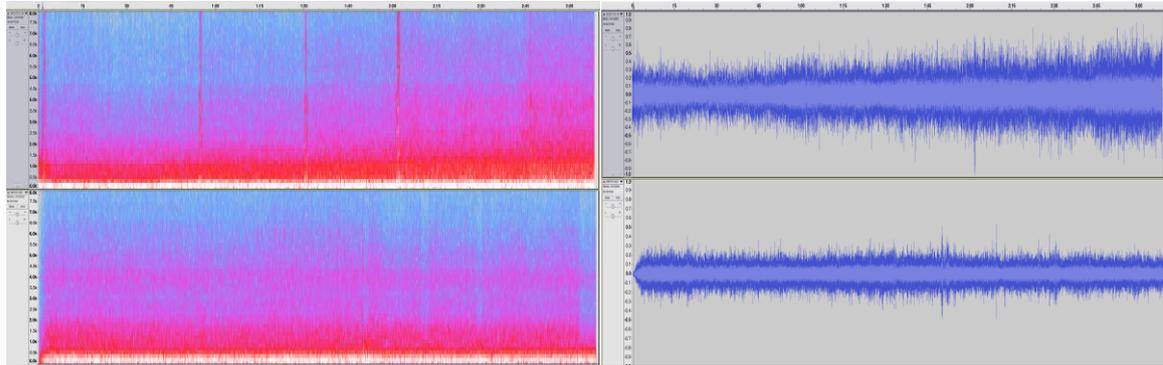


Figure 6. On the top, automobile recording and downwards, clinical pink noise. To the left, is observed the spectrogram and to the right the sound waveform.

The analysis in the presence of moderate rainfall (partially reduced view) as shown in Figure 7 shows sound amplitude variation at higher frequencies (from 2kHz) in the form of peaks, presenting uniform increases of about 20dB in the range from 2kHz up to 14kHz. In this specific case, the rain was not constant during the 5 minutes of recording, presenting considerable reduction at the instant 3:30. In addition, one of the reasons for the lack of change in the intensity of low frequency noise can be explained due to the insufficient sensitivity of the microphone used, which could already be within its maximum sound characterization limit. The sound energy of 80dB was only previously measured up to 4kHz frequencies and after moderate rain began, this amplitude was observed for frequencies up to 10kHz.

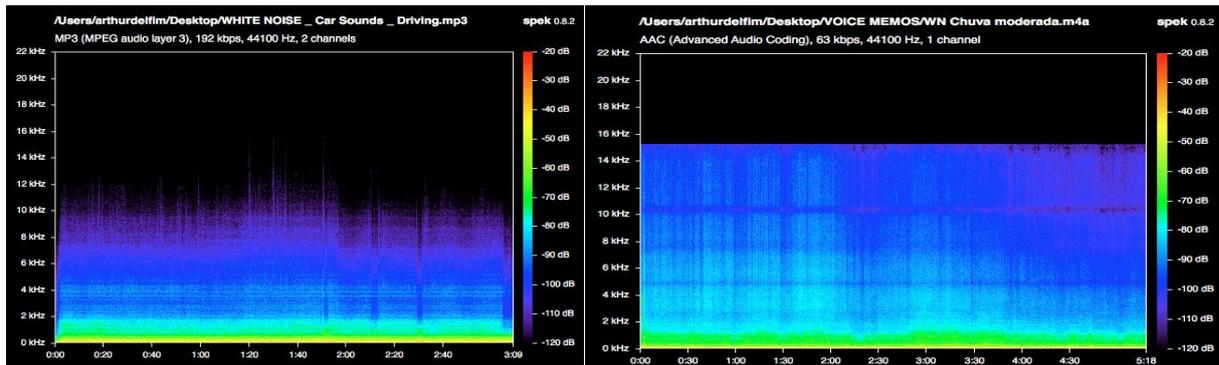


Figure 7. To the left, clinical pink noise, to the right, automobile recording for moderated rain condition at 80km/h.

Figure 8 shows the recording for the heavy rain condition (visibility very impaired). Despite the reduction in speed for safety reasons (60km/h), the sound amplitude inside the car was extremely high and the vertical increase pattern for higher frequencies was again observed.

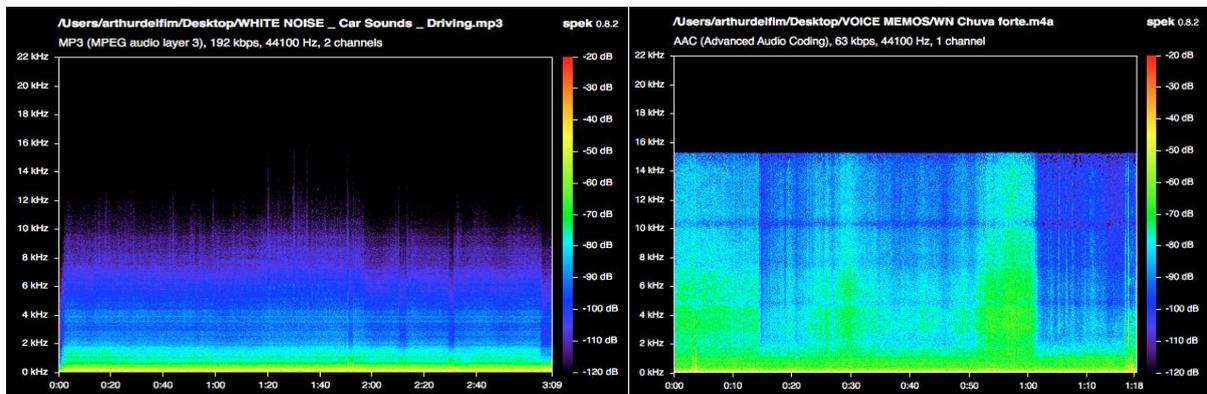


Figure 8. To the left, clinical pink noise, to the right, automobile recording for heavy rain condition at 60km/h..

5. CONCLUSIONS

The acoustics promoted by automotive vehicles in relation to road induced noise during long trips results in a type of noise clearly classified as pink noise. The speed and the presence of rain were able to change the spectral density of the recorded sound inside the vehicle. The increase in velocity widens the range of sound amplitude from low frequencies and upwards, without significant changes in the graphic profile of the spectrogram. The type of microphone used could have limited the present study in the determination of the sound over the low frequency band because, in some cases, the sound energy was too high to be stratified by the spectrogram analysis, especially in the condition of heavy rain. However, as the categorization of the spectrogram profile was the objective proposed by the present study, it was enough to validate the findings revealed by the work.

As the sound recorded in vehicles during long trips have proved to be clearly classified as pink noise, and as pink noise effectiveness for sleep induction is a literature consensus, this study promotes a vast field of research capable of saving many lives by the investigation of techniques applied to the automobile industry that are able to avoid the sleep induction from soundwaves.

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