Why A-weighting Network is inadequate for measurement of noise with high content of infrasound and Low Frequency Noise (ILNF)?

Hadi Asady[1], Mariana Alves-Pereira[2], Mohammad Bakhtiari[3], Adrian Fuente[4], Siamak Pourabdian[1], Farhad Forouharmajd[1,*]

[1] Department of Occupational Health Engineering, School of Health, Isfahan University of Medical Sciences, Isfahan, Iran.

[2] School of Sciences for Economics and Organizations, Lusofona University, Lisbon, Portugal.

[3] Behbahan Faculty of Medical Sciences, Behbahan, Iran.

[4] École d'orthophonie et d'audiology, Faculty of Medicine, Université de Montréal, Montreal, Quebec, Canada.

1 INTRODUCTION

Humans with normal hearing are able to detect sounds that fall within a frequency range from about 20 Hz to 20 kHz, with the upper limit dropping off somewhat in adulthood. Not all mammalian species are sensitive to the same range of frequencies, and most small mammals are sensitive to very high frequencies but not to low frequencies[1]. As can be seen in Figure 1 the human auditory system has threshold less than or equal to 10 dB for frequency range between 250-8000 Hz.

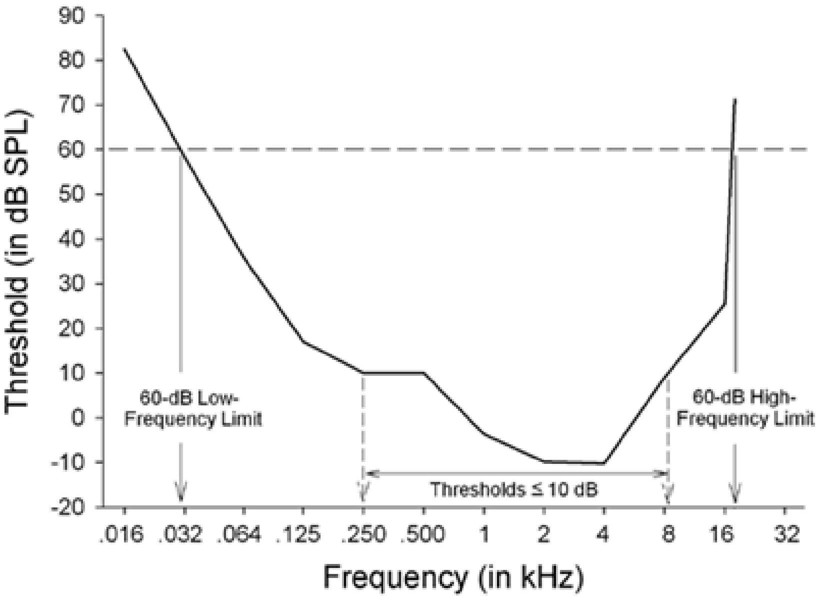

Figure 1: Audiogram showing the average human threshold for pure tones obtained in a sound field, hearing range is usually specified as the range of frequencies audible at a level of 60-dB SPL[2]

With decreasing of the frequency from the 250 Hz to lower frequencies the human hearing threshold increase and the sounds with level less than those thresholds are not auditable by most of humans. In the other words the sound level less than the human hearing threshold at the low frequencies (20<=f<=200 Hz)[3, 4] and infrasound (f<20 Hz) will not be detected and perception. This fact was reflected in the A-weighting network. The A-weighting filter was born with the work by Fletcher and Munson to determine loudness level contours for various sound levels. They selected 23 healthy, young males, whom were assumed to have good hearing. These subjects were exposed to a series of different, single, pure tones at different levels of loudness and asked to score the sounds for equal loudness. The tones, produced by valve oscillators and amplifiers, were presented to the listener by occluded (covering the ear) headphones. The basic range of 20 Hz to approximately 16 kHz was used because those were the limits of the equipment at the time[5]. Figure 2 shows the Fletcher and Munson loudness curves from their 1933 paper. Three years later, these curves were used in the first American standard for sound level meters developed by the Acoustical Society of America[6].

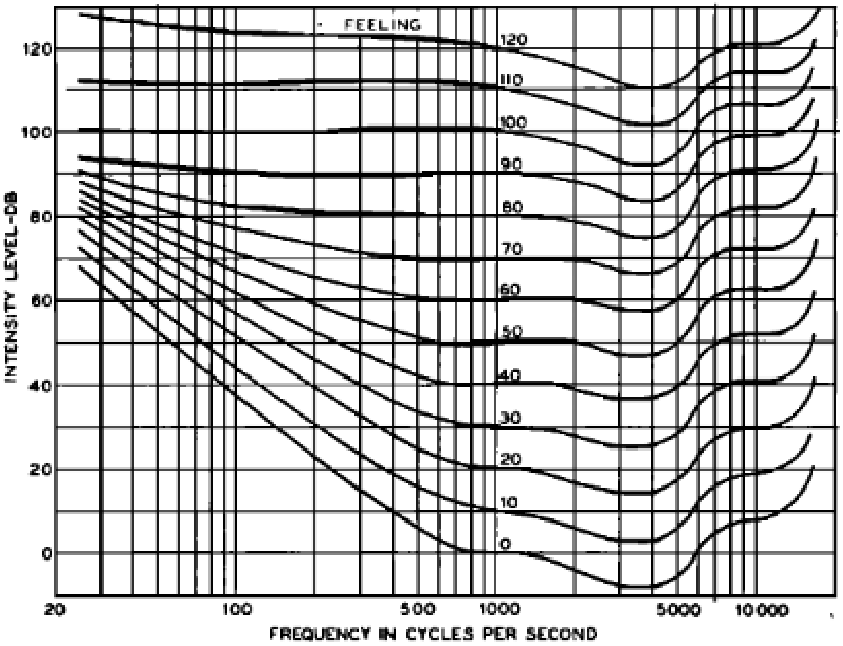

Figure 2: Loudness level counter[7]

Historically, the A weighting network on a sound level meter were derived as the inverse of the 40 dB Fletcher-Munson curves and used to determine sound level. Since A-weighting correction are too large for low frequencies[8] so we expect that carry out measurement of low frequency noise with using of this network underestimate the results too much. this problem was reported by some researchers. Alves-Pereira and et al. reported that the LFN components of noise-rich environments are most often unknown because noisy environments are usually only described by a dBA-level measurement[9]. Baliatsas and et al. showed that an issue of importance in terms of exposure characterization is the weighting method used to measure LFN. A-weighting is widely used in public health research. Adapted to the sensitivity of the average human ear, sound level meters set to the A-weighting network cannot efficiently evaluate the contribution of LFN components, since the human ear is less sensitive to very low-pitch or high-pitch noises[10]. The question is why A-weighting network is unappropriated for measurement of noises with high content of infrasound and low frequencies? Or approximately equal content of different frequencies including infrasound, low and high frequencies. We will try to answer to this question.

2 MATERIALS AND METHODS

At this part we used methods and equations which presented in the IEC 61672-1 as an international standard[11] for calculation of A, C and Z frequency-weighting networks.

2.1 Frequency-weighting C

For any frequency f in hertz, the C-weighting characteristic C(f) shall be calculated, in decibels, from:

$$C(f) = 10\log_{10}\left[\frac{f_4^2 f^2}{(f^2+f_1^2)(f^2+f_4^2)}\right]^2 dB - C_{1000}$$

Equation 1

Normalization constant C_{1000} represents the electrical gain, in decibels, needed to provide a frequency weighting of 0 dB at 1000 Hz. We can calculate $C(f)$ with using of formulas and values which presented in table 1 and 2.

Table1:

$f_1 = \left(\frac{-b-\sqrt{b^2-4c}}{2}\right)^{1/2}$	$f_4 = \left(\frac{-b+\sqrt{b^2-4c}}{2}\right)^{1/2}$	$f_r = 1000\ Hz$
$b = \frac{1}{1-D}\left[f_1^2 + \frac{f_L^2 f_H^2}{f_r^2}\right] - D(f_L^2 + f_H^2)$	$D = +\sqrt{D^2} = \sqrt{1/2}$	$c = f_L^2 \times f_H^2$
$f_L = 10^{1.5}$	$f_H = 10^{3.9}$	$f = f_r\left[10^{0.1(n-30)}\right]$

Table2:

Frequency (Hz)	10	12.5	16	20	25	31.5	40	50	63
n	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Frequency (Hz)	80	100	125	160	200	250	315	400	500
n	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
Frequency (Hz)	630	800	1000	1250	1600	2000	2500	3150	4000
n	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
Frequency (Hz)	5000	6300	8000	10000	12500	16000	20000		
n	**37**	**38**	**39**	**40**	**41**	**42**	**43**		

2.2 Frequency-weighting A

The A-weighting characteristic $A(f)$ shall be calculated, in decibels, from:

$$A(f) = 10\log_{10}\left[\frac{f_4^2 f^4}{(f^2+f_1^2)(f^2+f_2^2)^{1/2}(f^2 f_3^2)^{1/2}(f^2 f_4^2)}\right]^2 dB - A_{1000}$$

Equation 2

Normalization constant A_{1000} represents the electrical gain, in decibels, needed to provide a frequency weighting of 0 dB at 1000 Hz. We can calculate $A(f)$ with using of formulas and values which presented in table 2 and 3.

Table 3:

$f_1 = \left(\frac{-b-\sqrt{b^2-4c}}{2}\right)^{1/2}$	$f_4 = \left(\frac{-b+\sqrt{b^2-4c}}{2}\right)^{1/2}$	$f_r = 1000\ Hz$
$b = \frac{1}{1-D}\left[f_1^2 + \frac{f_L^2 f_H^2}{f_r^2}\right] - D(f_L^2 + f_H^2)$	$D = +\sqrt{D^2} = \sqrt{1/2}$	$c = f_L^2 \times f_H^2$
$f_L = 10^{1.5}$	$f_H = 10^{3.9}$	$f = f_r\left[10^{0.1(n-30)}\right]$
$f_A = 10^{2.45}$	$f_2 = \left(\frac{3-\sqrt{5}}{2}\right)f_A$	$f_3 = \left(\frac{3+\sqrt{5}}{2}\right)f_A$

2.3 Frequency-weighting Z

For any frequency in the range of a sound level meter, the Z-weighting characteristic $Z(f)$shall be given, in decibels, by

$$Z(f) = 0\ dB$$

Equation 3

2.4 Converting formula

The formula for converting octave-band sound pressure levels into sound levels on the X-weighting network is:

$$L_{X-Weighing} = 10\log_{10}\left[\sum_{i=1}^{n} log^{-1}(L_{pi}+F)/10\right] = 10\log_{10}\left[\sum_{i=1}^{n} 10^{(L_{pi}+F)/10}\right]$$

Equation 4

$L_{X\text{-weighting}}$(dB): Sound level on the X-weighting network, X being C, A or Z.
L_{pi}(dB) = Sound pressure level for the i_{th} octave band,
F(dB) = Correction factor,

3 RESULTS

With using of formulas 1, 2,3, weight values related to the three different weighting network including C, A, Z were calculated at different frequencies (related to the one-third octave bands) (see table 4). As you can see in table 4 highest weight was related to the frequency 10(Hz) for both A and C weighting network. The weighing increase with increasing of frequency from 10 to 5000 Hz and 10 to 160 Hz in the A and C weighing network respectively and after those frequencies starting to drop. For C-weighing network weight for nine frequencies including 200, 250, 315, 400, 500, 630, 800, 1000, 1250(Hz) are zero (0 dB) while in the A-weighing network just frequency 1000 Hz have zero (0 dB) weight. Weighing for Z networks was zero (0 dB) for all frequencies.

Table 4: Sound level conversion chart from flat response(Z) to A and C weightings.

Nominal frequency (Hz)	Frequency weightings (dB)		
	A	C	Z
10	-70.4	-14.3	0
12.5	-63.4	-11.2	0
16	-56.7	-8.5	0
20	-50.5	-6.2	0
25	-44.7	-4.4	0
31.5	-39.4	-3	0
40	-34.6	-2	0
50	-30.2	-1.3	0
63	-26.2	-0.8	0
80	-22.5	-0.5	0
100	-19.1	-0.3	0
125	-16.1	-0.2	0
160	-13.4	-0.1	0
200	-10.9	0	0
250	-8.6	0	0
315	-6.6	0	0
400	-4.8	0	0
500	-3.2	0	0
630	-1.9	0	0
800	-0.8	0	0
1000	0	0	0
1250	+0.6	0	0
1600	+1	-0.1	0
2000	+1.2	-0.2	0
2500	+1.3	-0.3	0
3150	+1.2	-0.5	0
4000	+1	-0.8	0
5000	+0.5	-1.3	0

6300	-0.1	-2	0
8000	-1.1	-3	0
10000	-2.2	-4.4	0
12500	-4.3	-6.2	0
16000	-6.6	-8.5	0
20000	-9.3	-11.2	0

Now with using of weighing values that was presented in the table 4 we want to calculate the sound total pressure of an artificial data (assumption this data was gathered with using of the sound level meter in Z weighing mode, actually this data set shows sound pressure levels at the different one-third octave frequencies in an imaginary place) with using of the equation 4. In this data set the sound pressure levels at the infrasound and low frequencies are higher than high frequencies. We can see same kind of data in some public and occupational settings[9, 12]. As you can see in table 5, for noise with high content of infrasound and low frequency noises, A-weighing network highly drop down the total sound pressure in comparison to the C and especially Z weighting networks.

Table 5:

Nominal frequency (Hz)	Artificial data(dB)	A(dB)	Ad-A(dB)*	C(dB)	Ad-C(dB)	Z(dB)	Ad-Z(dB)
10	100	-70.4	29.6	-14.3	85.7	0	100
12.5	98	-63.4	34.6	-11.2	86.8	0	98
16	96	-56.7	39.3	-8.5	87.5	0	96
20	94	-50.5	43.5	-6.2	87.8	0	94
25	92	-44.7	47.3	-4.4	87.6	0	92
31.5	90	-39.4	50.6	-3	87	0	90
40	88	-34.6	53.4	-2	86	0	88
50	86	-30.2	55.8	-1.3	84.7	0	86
63	84	-26.2	57.8	-0.8	83.2	0	84
80	82	-22.5	59.5	-0.5	81.5	0	82
100	80	-19.1	60.9	-0.3	79.7	0	80
125	78	-16.1	61.9	-0.2	77.8	0	78
160	76	-13.4	62.6	-0.1	75.9	0	76
200	74	-10.9	63.1	0	74	0	74
250	72	-8.6	63.4	0	72	0	72
315	70	-6.6	63.4	0	70	0	70
400	68	-4.8	63.2	0	68	0	68
500	66	-3.2	62.8	0	66	0	66
630	64	-1.9	62.1	0	64	0	64
800	62	-0.8	61.2	0	62	0	62
1000	60	0	60	0	60	0	60
1250	58	+0.6	58.6	0	58	0	58
1600	56	+1	57	-0.1	55.9	0	56
2000	54	+1.2	55.2	-0.2	53.8	0	54
2500	52	+1.3	53.3	-0.3	51.7	0	52
3150	50	+1.2	51.2	-0.5	49.5	0	50
4000	48	+1	49	-0.8	47.2	0	48
5000	46	+0.5	46.5	-1.3	44.7	0	46
6300	44	-0.1	43.9	-2	42	0	44
8000	42	-1.1	40.9	-3	39	0	42
10000	40	-2.2	37.8	-4.4	35.6	0	40
12500	38	-4.3	33.7	-6.2	31.8	0	38
16000	36	-6.6	29.4	-8.5	27.5	0	36
20000	34	-9.3	24.7	-11.2	22.8	0	34
Total Sound Pressure Level(dB)			73.68		96.44		104.33

* Artificial data(dB)+A(dB)= $L_{pi} + F$

3.1 Discussion

American Conference of Governmental Industrial Hygienists recommend 85 dB(A) for 8-hour exposure with noise in the occupational settings[13]. As you can see in the table 5 if we have a place (occupational or non-occupational) which the most of the noise energy transferred by the infrasound and low frequencies, we will not detect it if we use of A-weighing network for the noise level measurements. Since the calculated total sound pressure level with using of A-weighting network (73.68 dB) was more less than occupational noise exposure standards (85 and 90 dB(A) recommended by ACGIH and OSHA respectively for 8 hours' exposure) so planning for noise control is not needed in such situations. In such condition, we can expect that hearing system damage not be occurs and other demonstrated health effects of high-level of noise exposure such as cardiovascular diseases, annoyance, cognitive development and hyperactivity in vulnerable population groups such as children, anxiety, angiocardiopathy, and impaired hormone secretion not be seen[10, 14].
However, some of studies have shown than exposure of people with noise in occupational or non-occupational settings also under the recommended standards levels could increase some health and Well-being problems between them. Many studies tried to show that these kinds of problems are attributed to the infrasound or low frequency noise exposure[15, 16]. KP Waye reported that having exposure with low frequency noise could cause sleep disturbance, reduced Wakefulness/greater fatigue, reducing of the work performance and also hearing loss, annoyance[17]. Also, JA ALVES and et al. reported than low-frequency noise is an agent that interferes with the performance of work tasks[18]. In addition to these kinds of effects some studies reported that exposure with low frequency noise at sufficiently high SPLs (Sound Pressure Levels) induce vibrations mainly in the chest and stomach and may cause a multi symptom disease called vibro-acoustic-disease (VAD) in long term exposure[17, 19]. With looking of these studies specially about VAD we can realize that the SPL has an important role in causing of those problems but with using of A-wreathing network the SPL was underestimated and also, we could not recognize the places with high content of infrasound and low frequency noise, at this situation so we will not have preventive infrasound and low frequency exposure control strategy.

3.2 Conclusion

It is obvious that measurement of noise level in all kind of places (occupational or non-occupational) with using of A-weighting networks underestimated the total sound pressure level. Using of this network will not show us the places with high content of infrasound and low frequency noise so we will under noise effect without we could recognize it. So, at these situations using of Z-weighting network will show the real sound levels and different frequencies including infrasound and low frequencies.

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