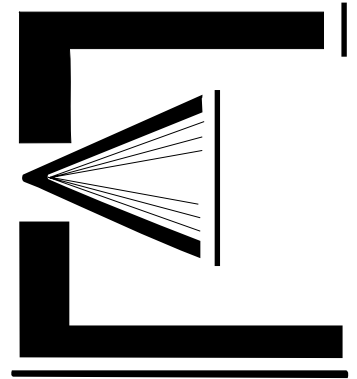




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A Division of
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Acoustic Characterization of Footfall Noise

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Abstract

Existing literature concerning footfalls is primarily focused on its transmission between spaces, such as a floor/ceiling's Impact Isolation Class. This study sought to measure the sound power spectra produced by footfalls on eleven different floor surfaces using both human subjects and a standard tapping machine. Within the University's reverberation room, fourteen subjects (7 male & 7 female) walked on each floor surface while wearing three different types of footwear: leather-soled shoes with hard heels, rubber-soled shoes with rubber heels, and sneakers. Sound power spectra for each condition were measured in 1/3 octaves using the procedures of ISO 3741. A tapping machine was also used on each floor profile using both the standard drop weights and with cored samples of the same test shoe soles attached to the bottom of the weights with magnets.

The data for each floor profile were averaged by shoe type. A total of 143 average sound power spectra were generated, based on eleven floors with thirteen averages per floor (3 male shoes, 3 female shoes, 6 shoed tapping machines, and 1 bare tapping machine). 95% confidence intervals were calculated for the human subject data.

The results for leather-soled shoes on harder surfaces such as oak, ceramic tile, and bare sub-floor produced the most sound power, with a spectral concentration in the 400 Hz – 800 Hz bands for male subjects and 800 Hz to 1250 Hz bands for the female subjects. Comparisons between other floor profiles and shoes types were made. The effects of adding rubber-backed commercial carpet directly onto concrete, adding rubber padding under carpet, using different sheet vinyl thickness were studied. Correlations between the sound power spectra produced with human walkers versus a tapping machine (both bare and with cored shoes), including the use of correction factors on tapping machine data to predict human spectra were investigated.

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Purpose

This study investigated the sound power spectra of human and tapping machine footfall noise within a room using a variety of shoes and floor surfaces.

Background and Procedure

Introduction

Footfall noise can be a significant component of activity noise in occupied rooms, particularly lecture halls and assembly spaces. Empirical evidence suggests that noise from footfalls is highly dependent on floor treatments within a given indoor architectural environment. Acousticians need to be able to determine how loud footfall noise might be within a space, for example, when an architect specifies an alternative to carpet in a given aisle-way. The acoustic consequences of harder floor surfaces can become important in the case of audience members leaving their seats during a performance, along with other circumstances.

The vast majority of published acoustic data regarding footfall noise pertains to the acoustic spectrum in spaces *below* the source room, and the resultant Impact Isolation Class (IIC) rating for the floor/ceiling. Some examples of existing research include [2-4,7-9,10,12]. While these data are important for tenants living in multi-story, multi-family dwellings, this study seeks to quantify the sound power spectra generated *in the same space* as the footfalls themselves. The relatively little information there is concerning such intra-room impact noise appears to be primarily qualitative [3,6,12].

The University's reverberation room is an appropriate space to conduct these sound power measurements. Reverberation rooms enable measurements in a diffuse field environment, controlling the effects of directivity and absorptivity. Measurements were

conducted as outlined in ISO 3741, *Determination of Sound Power Levels of Noise Sources using Sound Pressure-Precision Methods for Reverberation Rooms* [5]. Room dimensions, volumes, and proposed configurations were verified for compliance with ISO 3741.

It should be noted the University of Hartford's reverberation room underwent independent ISO qualification for diffuse fields during March 2006. Utilizing the procedures described in ISO 3741 Annex E, the chamber qualified for diffuse field testing in all 1/3 octave bands from 100 – 10,000 Hz [10]. The University's Brüel & Kjær Type 3923 boom microphone was configured to traverse a maximum circumferential path while traveling no closer than 1 meter to any surface within the reverberation room, so as to comply with ISO 3741. The boom motor was set to a 32 second period for each circumference. Each test floor profile was also placed at least 1 meter from the walls.

The ISO 3741 comparison method uses a reference source. An ILG reference sound source (RSS), manufactured by ILG Industries, Chicago, IL, was used for this purpose, as described in [1]. The radiation sound power levels of the RSS were tested prior to footfall measurements using a scanning sound intensity procedure to confirm the unit's compliance with published octave band sound power levels. Calibrated sound intensity measurements were made with a Brüel & Kjær Type 3520 intensity probe attached to a Brüel & Kjær 3590 Pulse Portable Analyzer System. The intensity probe was used with two different pairs of Brüel & Kjær phase-matched microphones: Type 4183 ½" with a 12-mm spacer and Type 4235 ¼" with a 6-mm spacer. This enabled a measurement range of 100 Hz–10,000 Hz. The RSS was placed within a "shoe box" shaped control volume with five rectangular sides, delineated using thin rods and string. The control surface measured approximately 1.4 meters high by 1 meter wide by 1 meter long, with a total area of about 6.6 m². A scanning wand technique was used to average the sound intensity over each surface during a 30 second time

period. The average sound intensity on each side was combined with the corresponding surface area to sound power using the relation $W = IA$. The total sound power spectrum was computed by summing the values from the five sides. The result of the sound intensity tests confirmed the ILG deviated less than ± 1 dB from the published values in [1] over the frequency span 100 – 6,300 Hz, and measured 2 dB and 3 dB below [1] in the 8 kHz and 10 kHz bands, respectively. These bands were adjusted accordingly in the Pulse Sound Power software, described below.

For this project, the objective was to test a range of floors typically used in public venues, including those used in concert halls. The 11 floor profiles chosen are listed in Table 1, below. It should be noted the components of Profiles #2-11 include additions to Profile #1 (poured concrete), and that each profile, except Profiles #1 and #3, was installed on Profile #2 (wooden sub-floor). The decision to construct individual wooden sub-floors for each floor enabled authenticity in construction, as well as consistent contact with the underlying concrete during testing.

Floor Profile	Description
1	Poured Concrete, 3" thick
2	Profile 1, plus ¾" wood sub-floor
3	Profile 1, plus rubber-backed short pile nylon carpet
4	Profile 2, plus rubber-backed short pile nylon carpet
5	Profile 2, plus 42 oz, looped, woven wool carpet, 0.25" pile height
6	Profile 5, with ¼" rubber pad below carpet
7	Profile 2, plus 0.056" sheet vinyl floor covering
8	Profile 2, plus 0.070" sheet vinyl floor covering
9	Profile 2, plus 0.076" sheet vinyl floor covering
10	Profile 2, plus ¾" tongue-in-groove oak flooring
11	Profile 2, plus 12"x12" Porcelain tile w/ 3/16" grout line

Table 1: List of Floor Profiles

The concrete sidewalk base was mixed using Quickrete™ Concrete Mix, and formed into 6 slabs of dimensions 1.5' x 2' by 3" thick. This enabled test subjects to walk 4 – 5 strides end-to-end. Poultry netting was used as steel reinforcement in the middle of the slab to prevent crack propagation. The netting was not visible on the outside once the forms were removed. The concrete was allowed a full cure of 28 days; no cracks were evident. During the curing process, the slabs were kept damp to prevent cracking. The weight of each slab was approximately 105 lbs, and thus the weight density for each slab was 11.7 lb/(ft*in_{thick}). This number is within the concrete weight density range for typical commercial floors of 9 to 12 lb/(ft*in_{thick}).



Figure 1: Profile 1, Poured Concrete

The 6 slabs were arranged in the reverberation room to create an ~9 foot long walkway, and placed on neoprene pads to isolate them from the reverberation room floor (See Figure 1). Thin strips of neoprene (2" long) were placed in between the slabs as well to prevent contact between the slabs.

The wooden sub-floors were constructed of tongue-in-groove ¾" plywood with dimensions of 9'4" long x 2'4" wide. Along the sides, 2 x 4's were attached underneath allowing the plywood to sit directly on top of the concrete slabs with the stiffening stud frame hanging on the outside. The 2 x 4's were cut to be 2" tall, so they would not make contact with the floor of the reverberation room when placed on the concrete walkway. Thus, the sub-floors were constructed so as to make continuous, solid contact with the concrete base as shown in Figure 2, at right. The



**Figure 2: (top) Schematic of Wooden Sub-floor on Concrete Slabs
(bottom) Actual Sub-floor**

sub-floors provided the proper base for several test materials such as the oak flooring, the sheet vinyl, etc., while providing an efficient means of switching profiles on top of the single set of concrete slabs.

Each floor profile was secured to the sub-floor in a unique manner. The rubber-backed commercial carpets were already backed with a “peel-and-stick” adhesive which was utilized in Profiles #3 and #4. However, Profile #4 had staples added along the edges. Profile #3 is shown below in Figure 3.



**Figure 3: Profile 3,
Rubber-Backed Carpet on
Concrete**



**Figure 4: Profile 9, Thick
Vinyl Sheet Covering on
Sub-floor**

The sub-floors were cleaned and spackled prior to applying adhesive for the vinyl flooring to ensure that the vinyl lay flat. A 100-lb roller was also utilized for the vinyl installation to prevent bubbles and produce a continuous bond. The vinyl was stapled as necessary to prevent curling at the edges. Figure 4 shows Profile #9.

For the tongue-in-groove oak floor, a layer of tar paper was placed between the oak and the wooden sub floor, as is typical for the construction of this floor type. The oak floor was nailed to the wood sub-floor with 1 ½" hard cut flooring nails. 2" screws were also used along the edges of the floor to keep it from moving relative to the sub-floor. Figure 5 shows

Profile #10 (oak flooring) during construction. Note the intermediate tar paper layer in Figure 5, at right.

The tile floor was made of 12" x 12" ceramic tiles and attached to the wood sub-floor with unsanded *Mapei* Premixed Adhesive and Grout. A 3/16" grout line was



Figure 5: Construction of Profile 10, Oak Flooring

used. The wool carpets were attached to the sub-floor using 0.50" staples along the edges.

Test Subjects

Fourteen test subjects participated in this study, and were selected from the University of Hartford student body and faculty. Seven were male and seven female, aged 19 to 50, and were selected on the basis of their shoe size and commitment to the project. They signed consent forms and were each compensated \$10.

A standard Brüel & Kjær Type 3207 tapping machine was also used to simulate footfalls. The Type 3207 tapping machine utilizes 5 weights of 500 grams each, impacting at 2 Hz. This resulted in an overall impact frequency of 10 Hz.

Three different types of shoes were utilized to collect data with all eleven profiles. Both male and female test subjects were recruited to walk on each floor profile with sneakers, rubber-soled shoes, and leather-soled shoes, corresponding to relatively soft, medium, and hard footwear. Details for each shoe are shown in the table below along with photos in Appendix B. Variation in women's shoe size was due to inconsistencies in brand-to-brand sizing. Shoes were chosen to fit all of the test subjects such that they could walk safely and consistently without slipping out of the shoes.

	Brand	Shoe Name	Size	Heel Material	Heel Width	Heel Length	Heel Thickness
Men's							
Leather Sole	Mercanti Fiorentini		13	wood	3 1/8"	3 1/4"	nominal 1"
Rubber Sole	Nunn-Bush		13	rubber	3 1/4"	nominal 4"	1"
Sneaker	Reebok	Classic	13	no heel	N/A	N/A	N/A
Women's							
Leather Sole	Ditto by Vanelli		9.5	plastic	2"	2 3/4"	7/8"
Rubber Sole	White Mountain		8.5	rubber	2 3/8"	2 1/2"	nominal 2"
Sneaker	Reebok	Classic Princess	9 wide	no heel	N/A	N/A	N/A

Two pairs of each shoe were purchased: one for the test subjects to wear and one additional pair for fitting to the tapping machine. The extra shoes were cored to match the 3 cm diameter of the tapping machine weights using a 1 1/4" hole saw and a drill press. (Figure 6, right) Figure 7, below, shows one cored sample. The cored shoes were then glued to grade N-42 neodymium "rare-earth" magnets, rated at 3340 gauss. The assembled cores were attached via magnetism directly to the tapping machine weights, which provided a strong, temporary bond (Figure 8). Visual monitoring during testing confirmed that negligible movement of the magnets relative to the hammers occurred.



Figure 6: Coring the shoes for the tapper



Figure 7: Cored Shoe



Figure 8: Magnets Attached to the Tapping Machine

For the five weights of the tapping machine, two cores were taken from the heel of the shoes, and three from the sole of the shoe. These numbers were chosen to simulate the actual ratio of heel-to-sole for a human gait. According to Winter [11], the ratio of heel-sole contact while walking is approximately 5:7. This corresponds to the heel making contact during 42% of the step. For the tapping machine, 2 of the 5 weights correspond to 40% of one tapping machine cycle. Given the finite number of 5 weights, this was considered an acceptable approximation of a human heel-sole ratio.

For the footfall measurement procedure, a different floor was tested each day. This ensured that the floor would not have to be switched in between the subjects, and thus the contact between the concrete walkway and the sub-floor could be maintained in an identical manner for each subject. Each subject walked in each of the three pairs of shoes each test day. A Brüel & Kjær Sound Power Type 7799 Software package was run using PULSE system version 10.0 to calculate the sound power from the pressure measurements using the comparison to the RSS.

The PULSE measurement system was calibrated each day. The procedure was to first calibrate the Brüel & Kjær Type 4144 microphone using a Brüel & Kjær Type 4213 calibrator, then to measure background noise and finally the radiated sound levels of the RSS using the same 32 second measuring period. The microphone was placed on a rotating boom that measured a spatial average of the sound pressure level in the room for each measurement. Each subject walked on the profile for a 32-second measuring period while wearing each of the three pairs of shoes. The length of the floor surfaces enabled the test subjects to accomplish 4 – 5 paces before reversing directions. Practice sessions were held with the subjects to ensure a consistent walking gait with minimized silences during

reversals. For safety and quality control, a closed-circuit video monitoring system was installed to observe subjects while they walked within the reverberation room.

Results

The data was averaged by floor and shoe. For example, for the concrete floor, all seven spectra for the men's sneaker were averaged together to create one spectrum. Then all seven spectra for the men's rubber sole on the concrete floor were averaged, and so on. These averaged spectra, as well as raw data for the tapping machine, are listed in Appendix A. With 6 different shoe averages per floor (3 male type and 3 female type) plus 7 tapping machine spectra (7 with shoes and 1 bare) and 11 different floors, a total of 143 total spectra are presented in Appendix A.

For some floor/shoe combinations, some 1/3 octave bands for certain subjects contained so little sound energy that they were more than 10 dB below the measured background spectrum. When this occurred, those subjects' data were eliminated from that frequency band's average. Affected bands are indicated in the averaged data with color-coded highlights, and in the graphs with an asterisk following the label for the affected band. Statistical 95% confidence intervals were also included on the graphs. For every band with fewer than 7 subjects in the average, the confidence intervals were adjusted to accommodate a smaller average. Since the confidence interval is dependent on sample size, reducing the number of samples increased the interval span in certain cases.

Figure 9 (below) shows the average men's leather sole spectrum on ceramic tile. Note the confidence intervals remain within ± 2 dB across the spectrum. Figures 10 and 11 show the men's leather sole on the oak and thin vinyl floorings, respectively. Note also that all

three hard surfaces demonstrated a broad spectral concentration in the 400 – 800 Hz region for male subjects wearing the leather sole/wooden heel shoes.

Figure 9: Men's Leather Sole on Ceramic Tile Floor

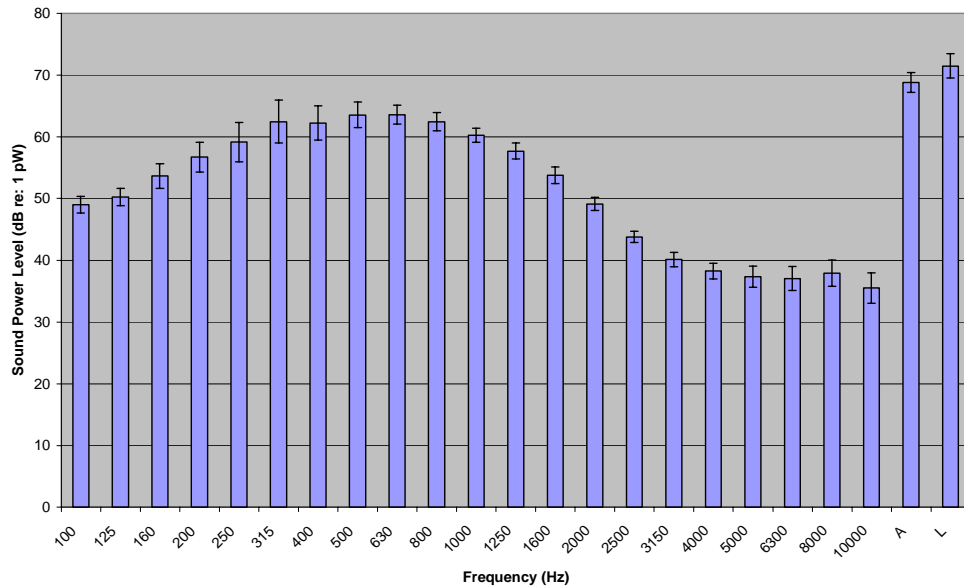


Figure 10: Men's Leather Sole on Oak Floor

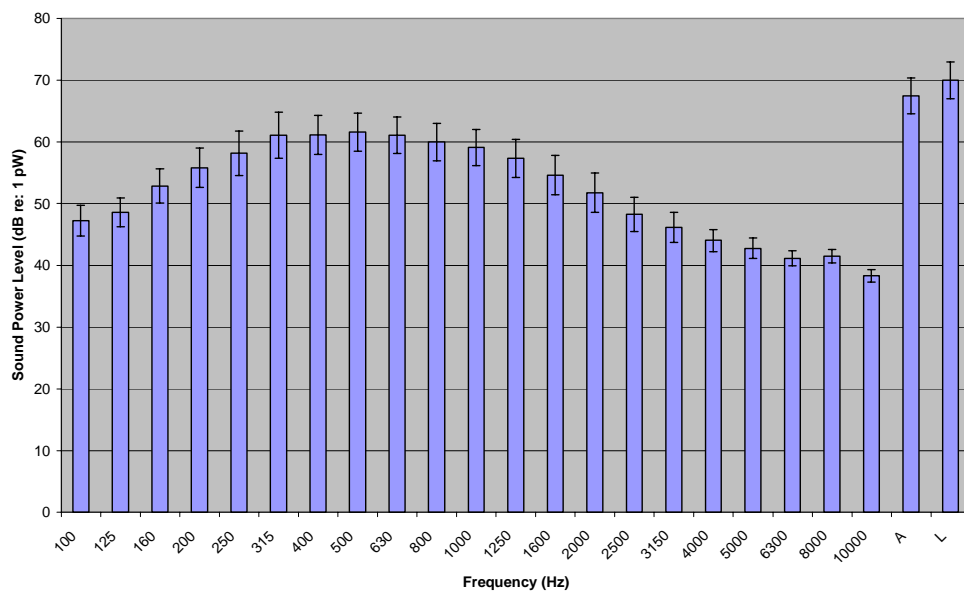
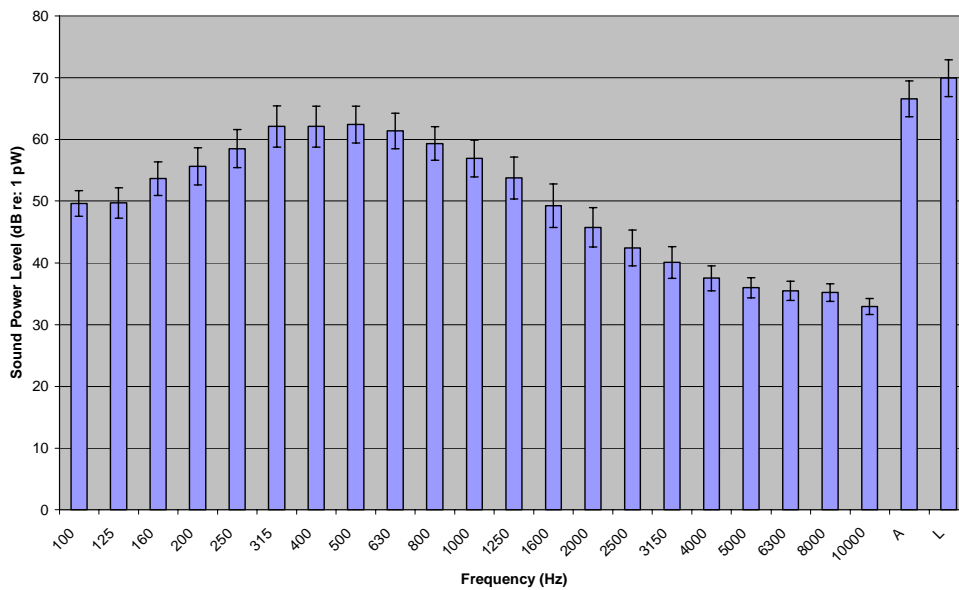


Figure 11: Men's Leather Sole on Thin Vinyl



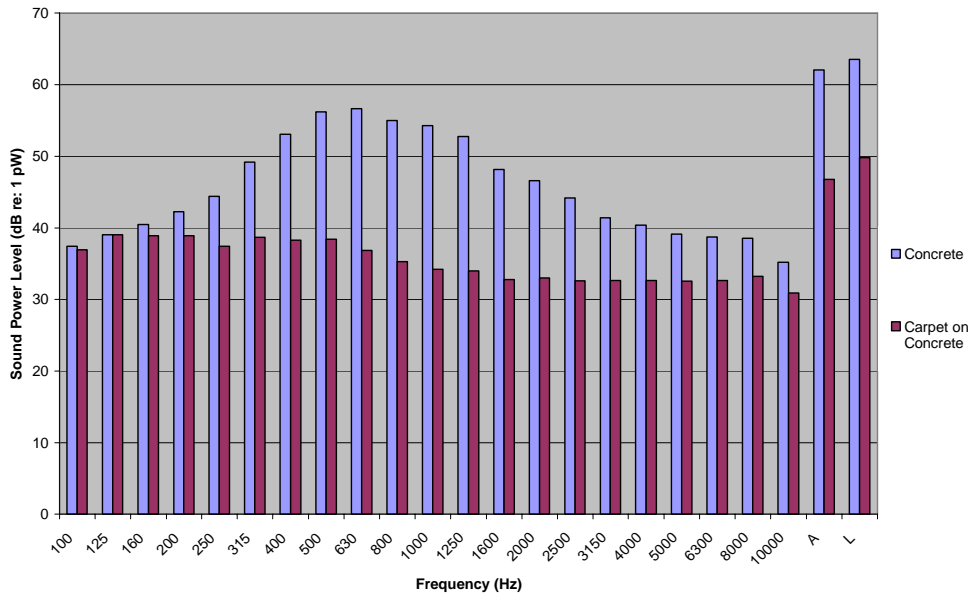
Initial comparisons were also made between similar floor types. For example, the effect of commercial rubber-backed carpet on concrete is presented, as well as comparing different vinyl sheet covering.

NOTE: Only the graphs for leather-soled shoes are reproduced here due to space constraints, and as these spectra show the most evident trends.

Bare Concrete vs. Carpet on Concrete

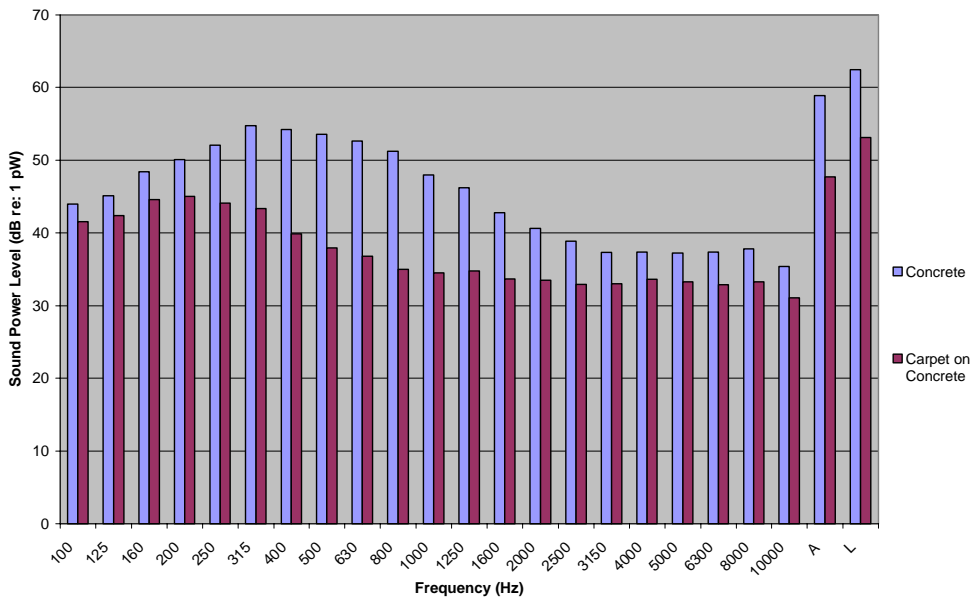
The addition of commercial rubber-backed carpet to the concrete walkway significantly decreased the measured sound power across the spectrum. Compared to the bare concrete, an overall sound power level decrease of 15 dBA was measured for the women's leather sole. It should be noted that the lowest overall sound power spectrums were produced on the carpet on concrete floor profile, *without the sub-floor*.

Figure 12: Women's Leather Sole



A similar spectrum can be seen for the men's leather sole with the same floor comparison. There is an overall decrease of approximately 10 dBA for the case of men's leather-soled shoe with carpet versus bare concrete.

Figure 13: Men's Leather Sole



Wooden sub-floor vs. Carpet on sub-floor

The addition of rubber-backed carpet onto the wooden sub-floor also demonstrated substantial attenuation across all frequency bands as compared to the bare sub-floor. The overall decrease was 29 dBA for the women’s leather sole, and approximately 20 dBA for the men’s leather-soled shoe.

Figure 14: Women's Leather Sole

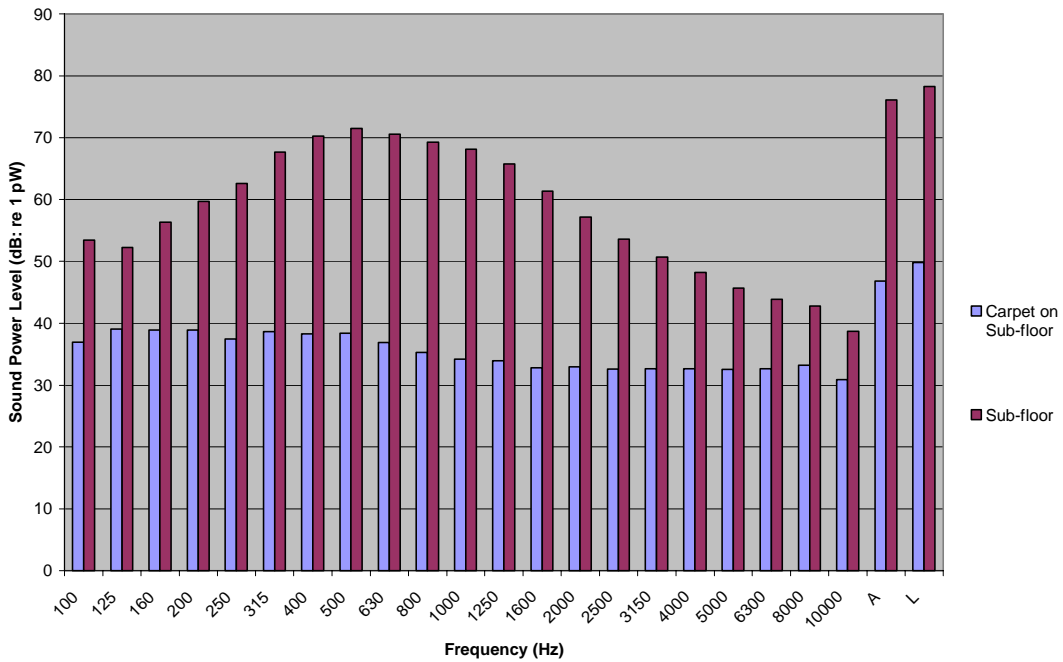
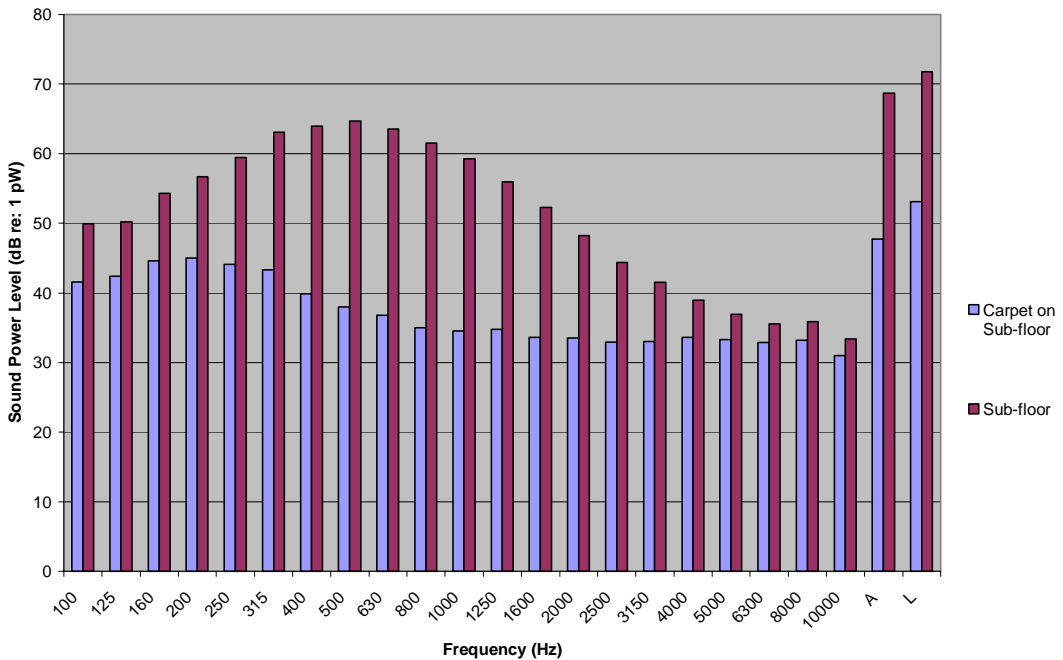


Figure 15: Men's Leather Sole



3 Vinyl Thicknesses

The 3 thicknesses of the vinyl showed insignificant variation due to sheet thickness. The maximum variation in any band did not exceed 3 dB for the case of both men's and women's leather-soled shoes on the vinyl surfaces. See Figures 16 and 17, below.

Figure 16: Women's Leather Sole

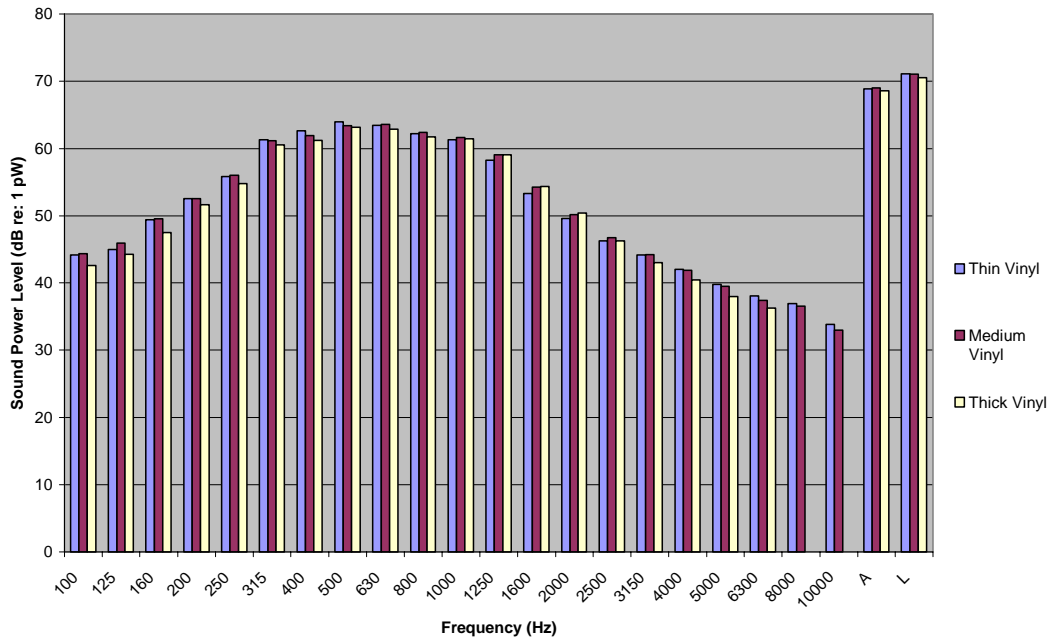
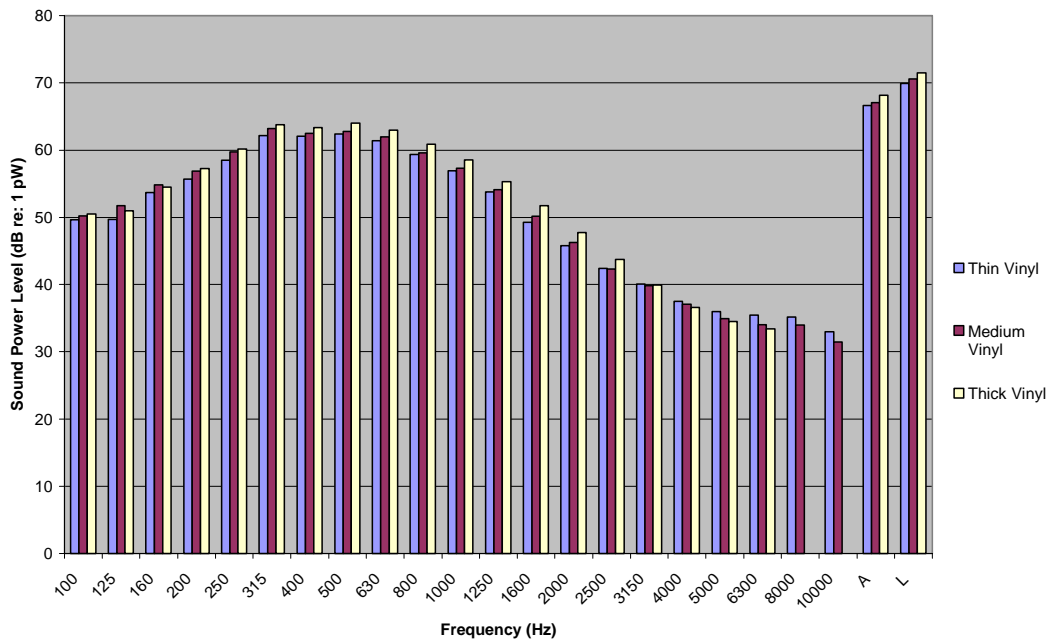


Figure 17: Men's Leather Sole



Vinyl on Sub-floor vs. Sub-floor Only

The vinyl provided an overall of 7 dBA attenuation for the women's leather sole as compared to the bare sub-floor. It demonstrated an overall attenuation of 2 dBA for the men's leather sole. Only the medium vinyl was used for the comparisons in Figures 18 and 19 below due to the minimal variation between vinyl samples.

Figure 18: Women's Leather Sole

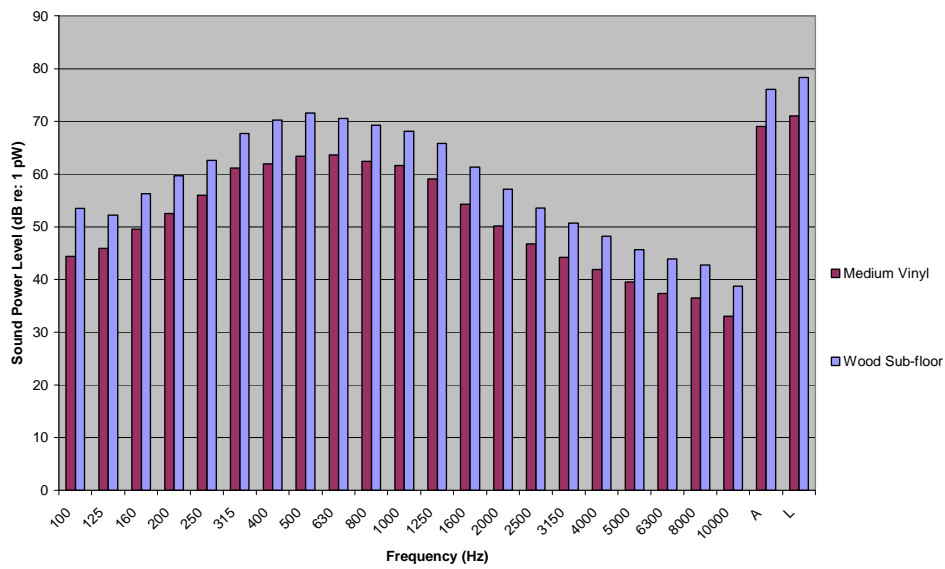
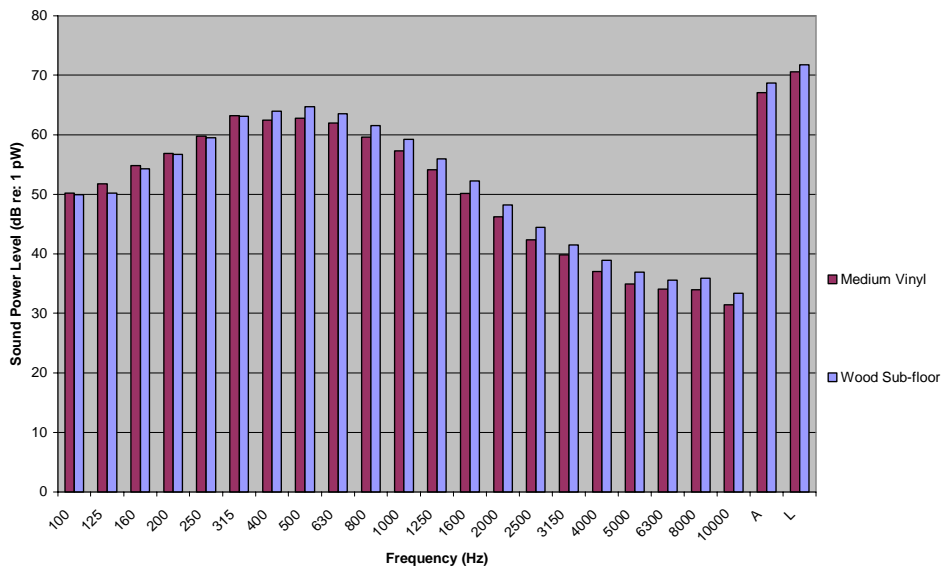


Figure 19: Men's Leather Sole



Wool vs. Wool w/ 1/4" Pad

The 1/4" rubber pad reduced the overall sound power level by about 9 dBA for the women's leather sole. See Figure 20, below. For the men's leather sole, adding the carpet pad attenuates the A-weighted level approximately 4 dB. See Figure 21, below.

Figure 20: Women's Leather Sole

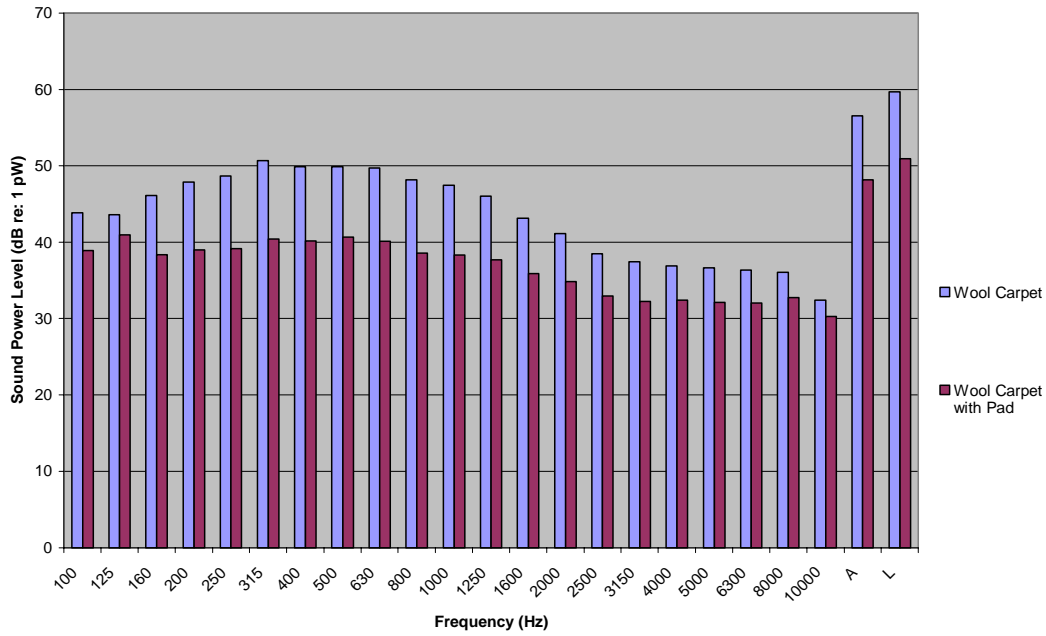
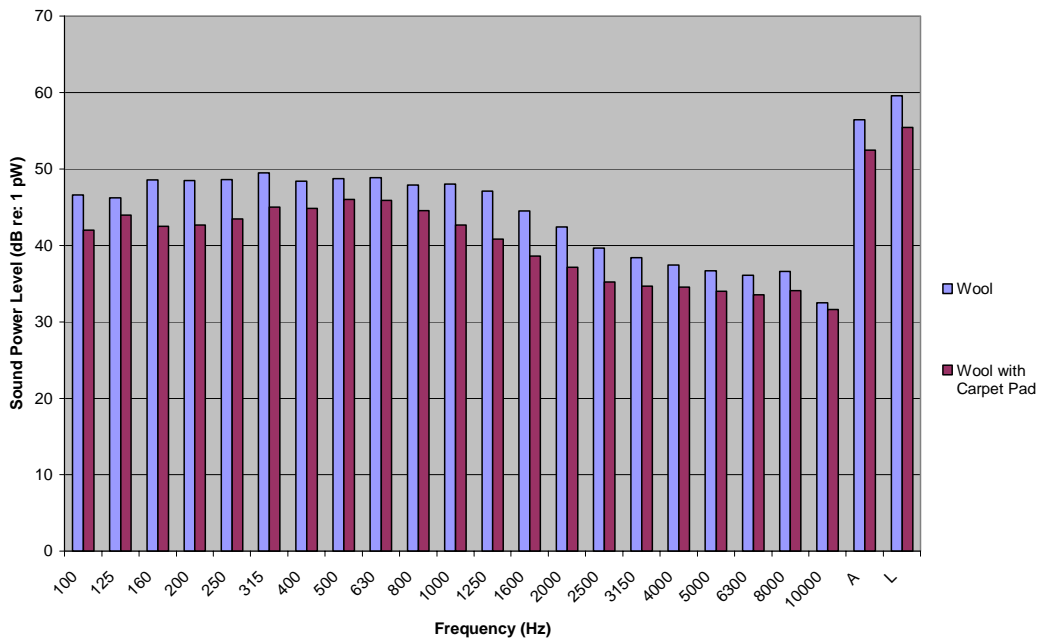


Figure 21: Men's Leather Sole



Shoed Tapping Machine

Since the tapping machine contacts the floor many more times each second than the walking test subjects, the sound power levels across the spectrum were understandably higher. In order to make a comparison between the human and the tapping machine spectrum, the tapping machine spectrum was scaled with a constant dB scaling factor across all frequency bands. The scaling factor was chosen for the best match between the two spectra and thus has a unique value for different shoes and floor combinations.

Two trends were discovered when comparing the shoed tapping machine spectra against the humans'. The first occurred for the case of hard shoes on hard floors (for example, a leather shoe on an oak or tile floor). With this combination, a constant dB correction factor could be added to the tapping machine spectra to approximate the human spectra. Figure 22 shows the similarity between the human subject data and a constant 24 dB correction factor applied to the case of women's leather shoes on an oak floor. Figure 23 shows the case of a 20 dB correction factor applied for men's leather shoes on an oak floor. This correction factor was dependent on both floor and shoe, however, and no general association or scaling factor could be determined that would be applicable for every case.

Figure 22: Women's Leather Sole on Oak Floor

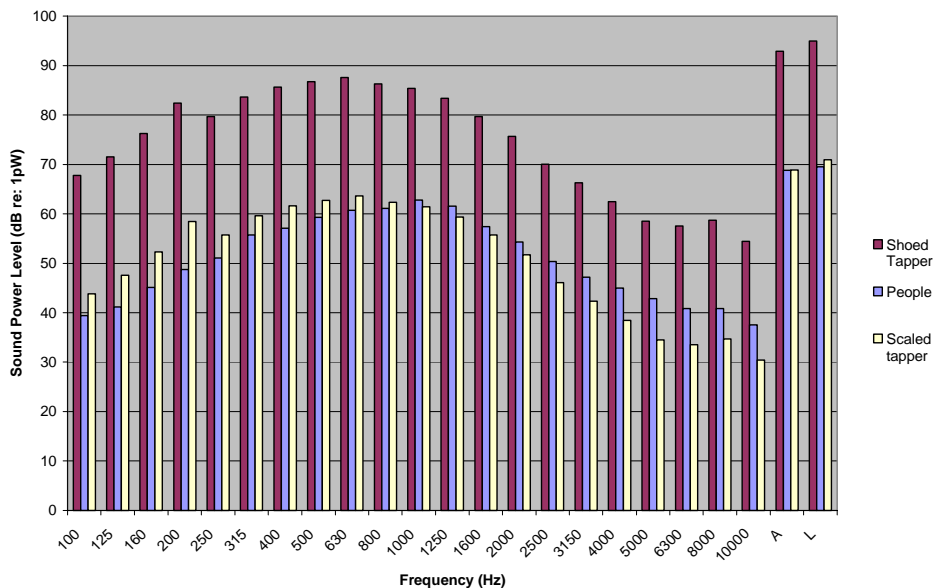
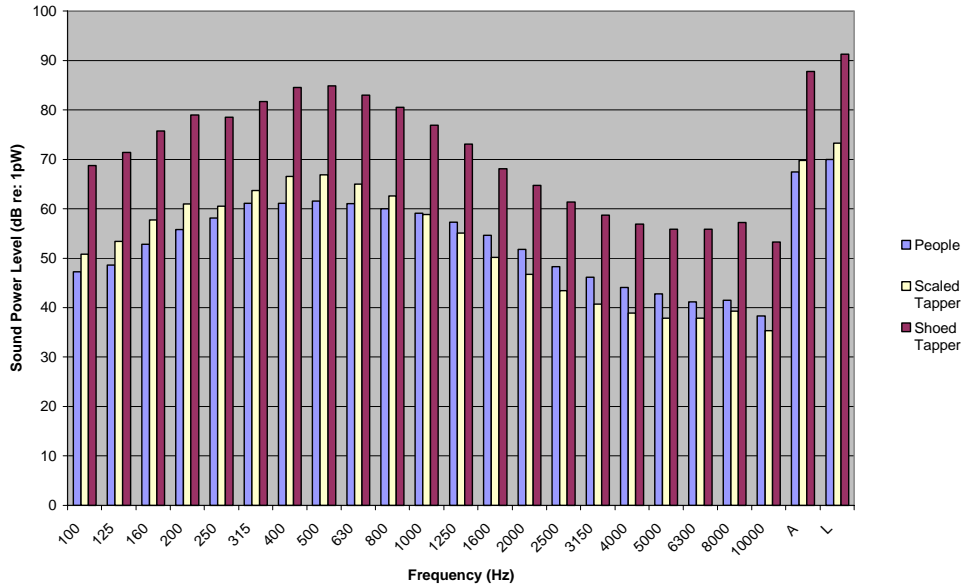


Figure 23: Men's Leather Sole on Oak Floor



However, none of the shoed tapping machines on soft, pliant floors (such as wool or the rubber-backed carpet) demonstrated a constant dB scaled relationship between shoed tapping machine spectra and human spectra. From Figures 24 and 25, below, it is evident that the shoed tapping machine spectra demonstrate a step drop-off in the mid-range frequencies that is not present in the human spectra. Due to this, a constant dB correction factor would not be sufficient to create an accurate comparison between the tapping machine and the human subjects on the soft floors.

Figure 24: Women's Sneaker on Carpet on Concrete

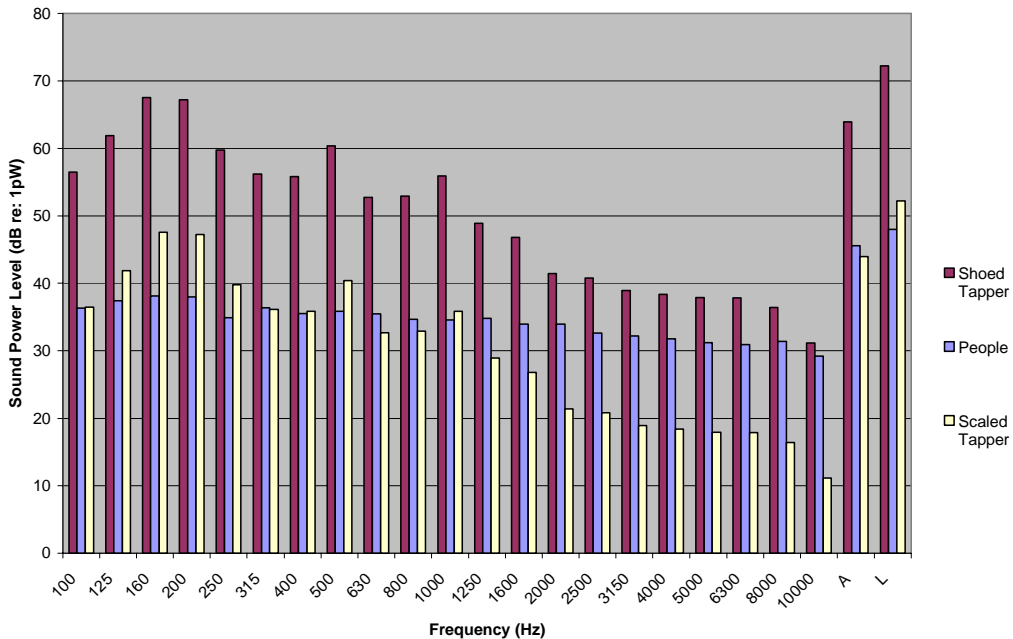
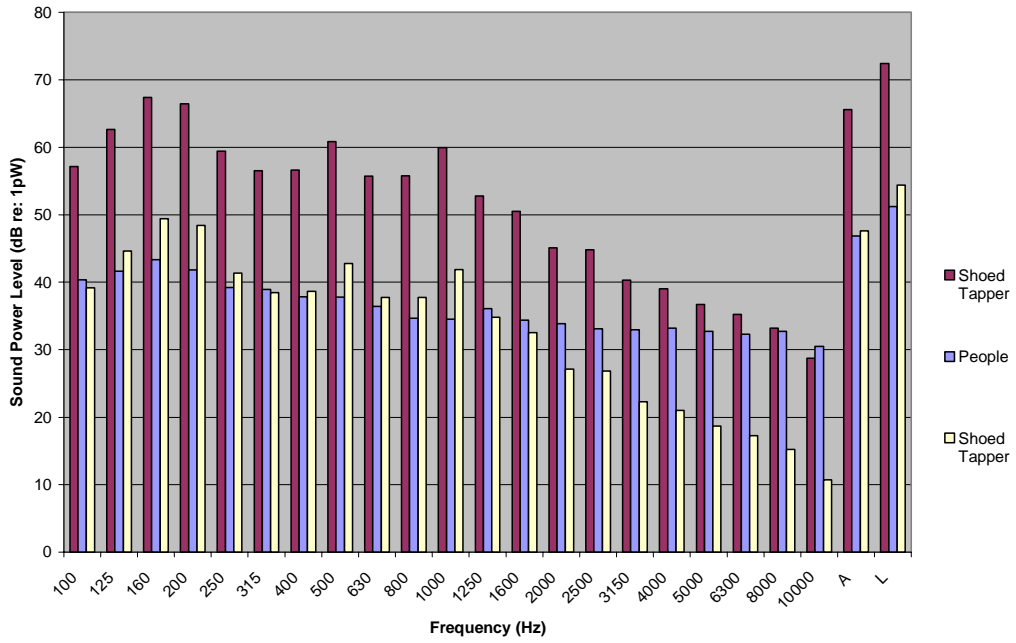


Figure 25: Men's Sneaker on Carpet on Concrete



The trends for each case are consistent, however. This suggests that a sloped, offset correction factor may be necessary to approximate the human spectrum for shoes on soft floors.

Figure 26: Women's Leather Sole on Carpet on Concrete

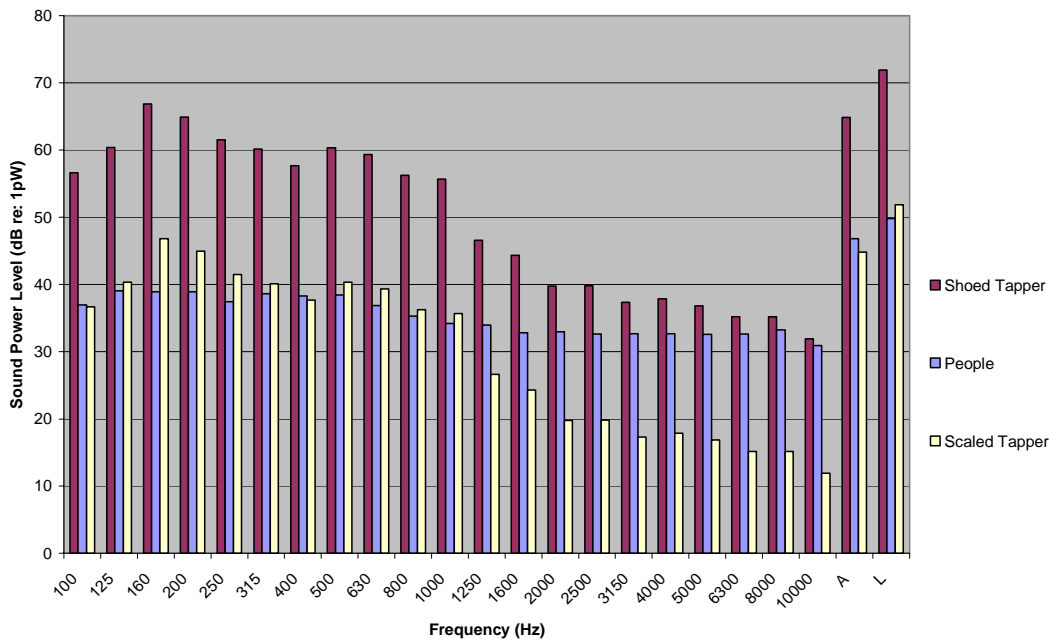


Figure 27: Men's Rubber Sole on Wool w/ Pad

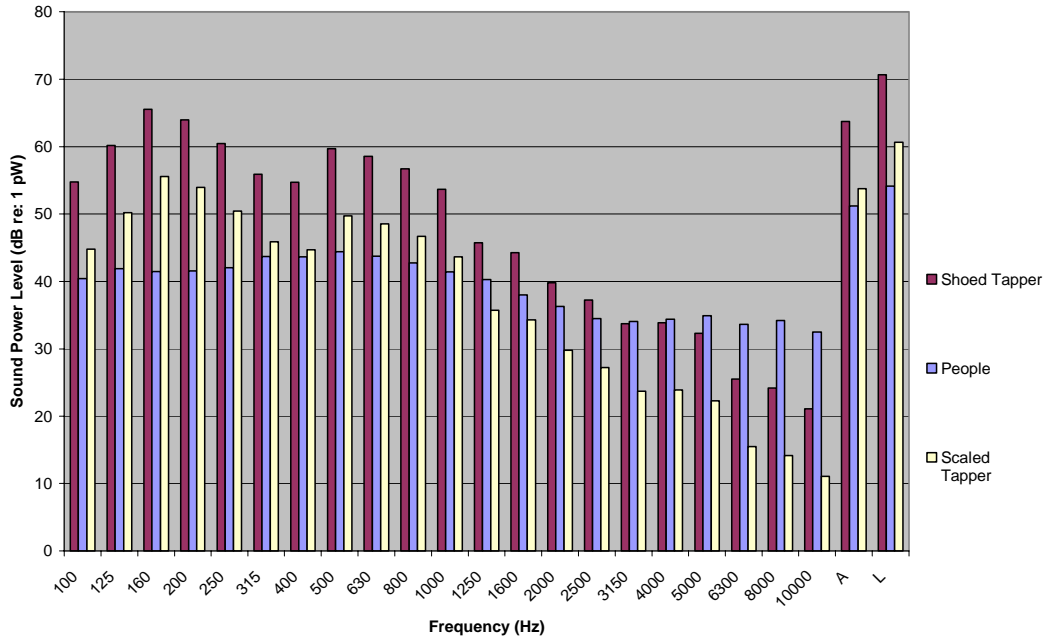


Figure 28: Women's Rubber Sole on Wool w/ Pad

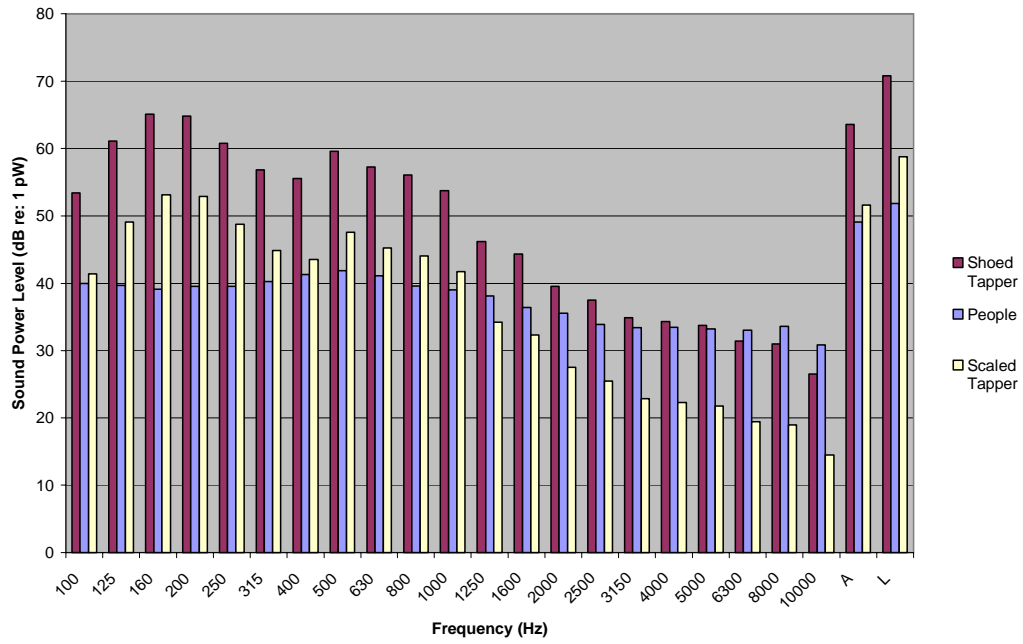
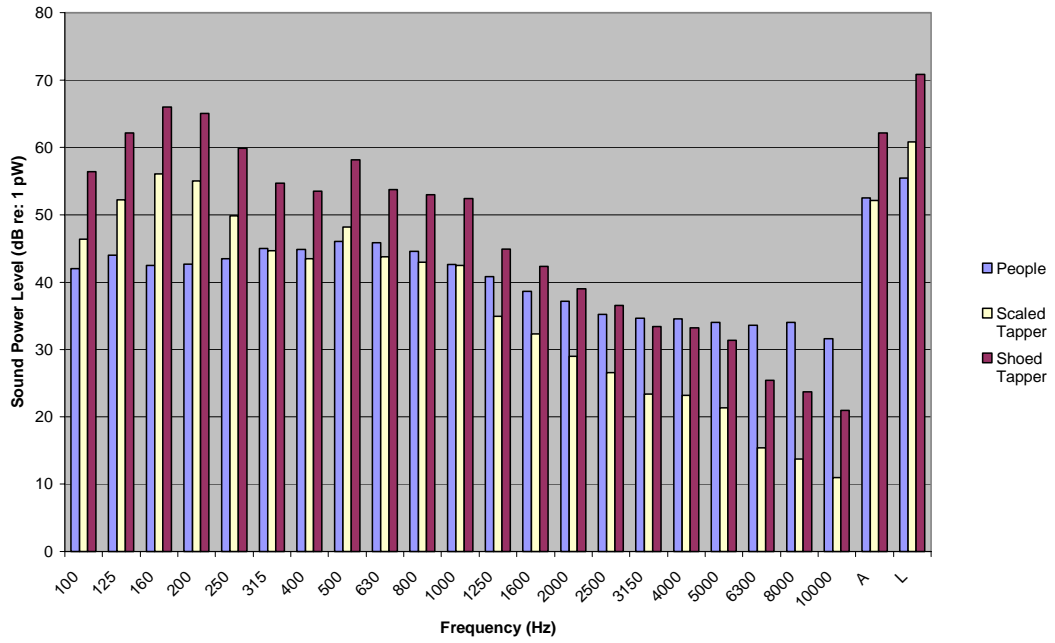


Figure 29: Men's Leather Sole on Wool w/ Pad



Bare Tapping Machine

The tapping machine was also used in the conventional manner, with the bare metal weights impacting each of the floor profiles. This setting produced spectra atypical of any of the shoes, and often produced highly tonal spectra and was therefore a poor simulator of human footfalls. Some different examples, showing a variety of shoes and floors, are shown in Figures 30-33 below. Only men's shoes are shown here, however similar trends exist in the women's spectra. For these graphs, the shoe in the title refers to the shoe worn by the human subjects. The tapping machine had bare weights in all cases.

Figure 30: Men's Sneaker on Oak Floor

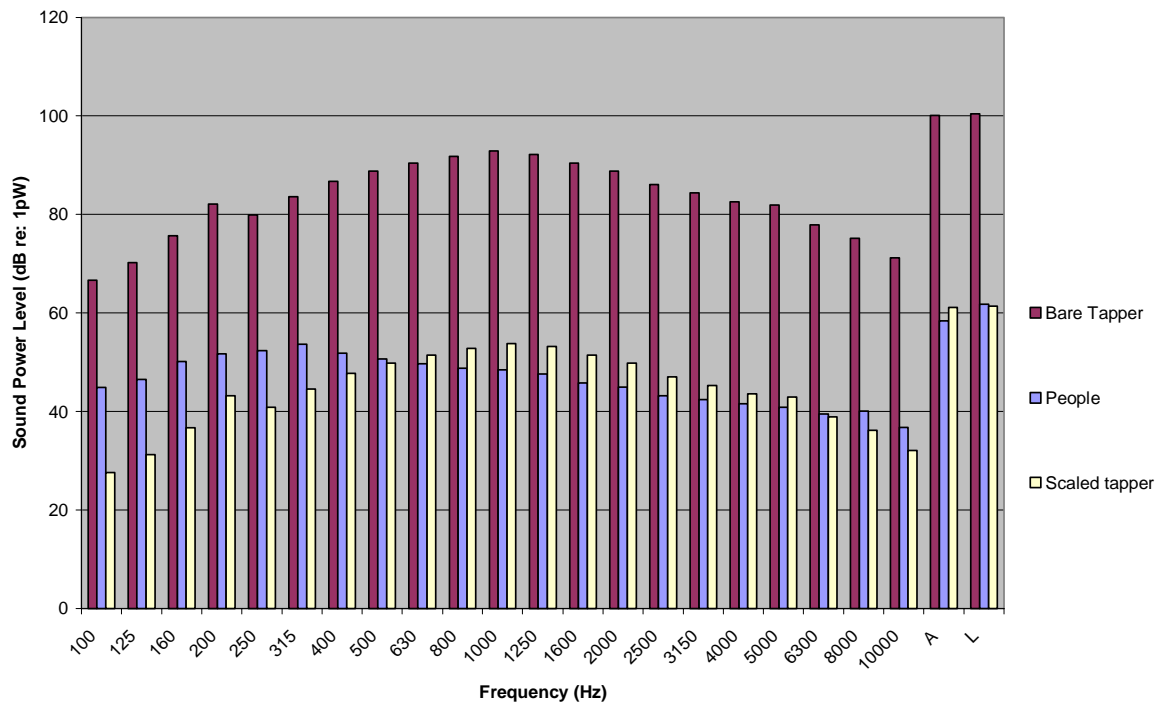


Figure 31: Men's Sneaker on Concrete Floor

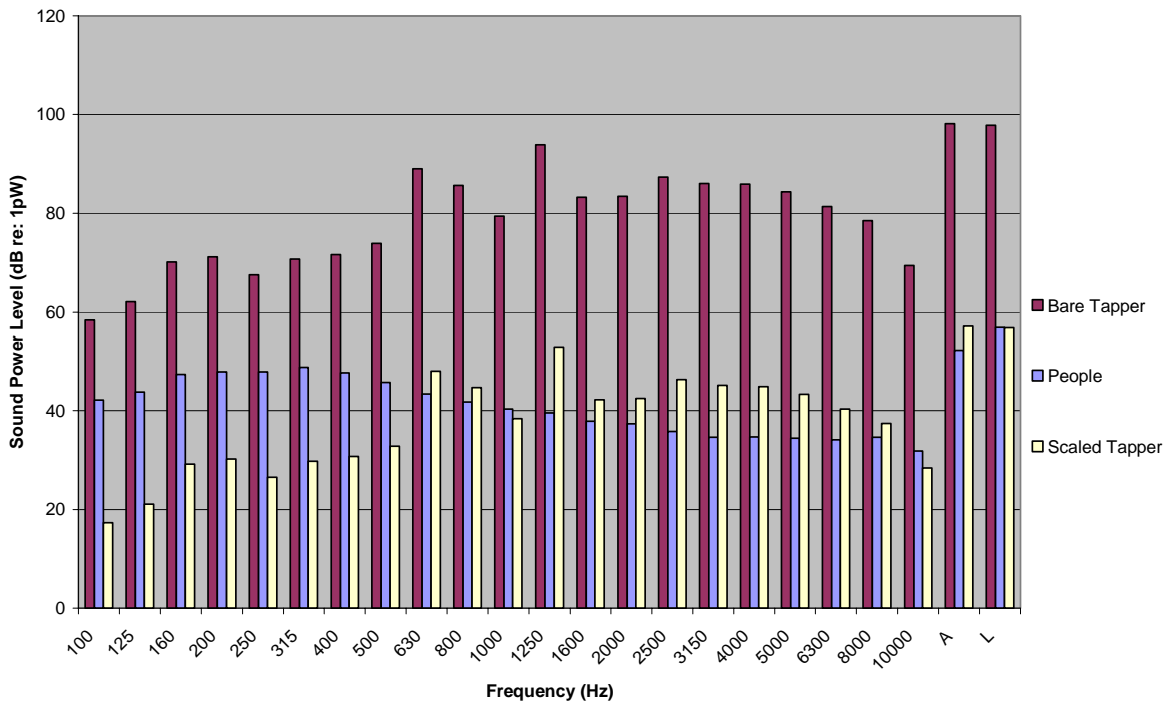


Figure 32: Men's Rubber Sole on Sub-floor

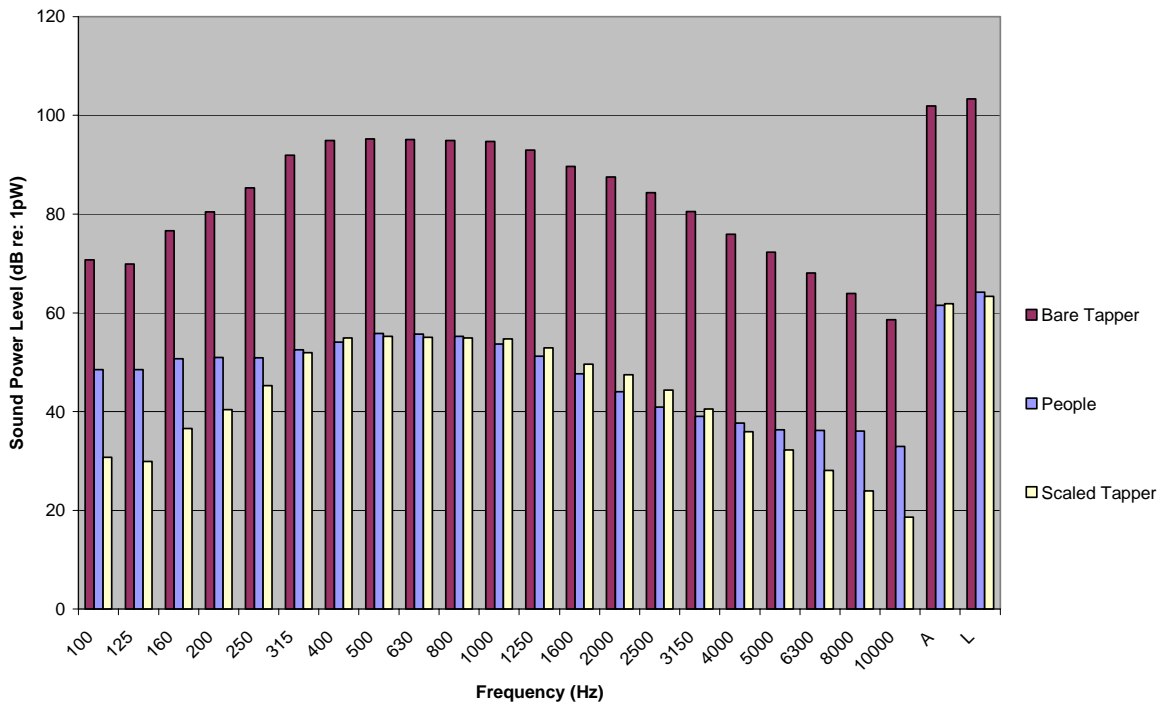
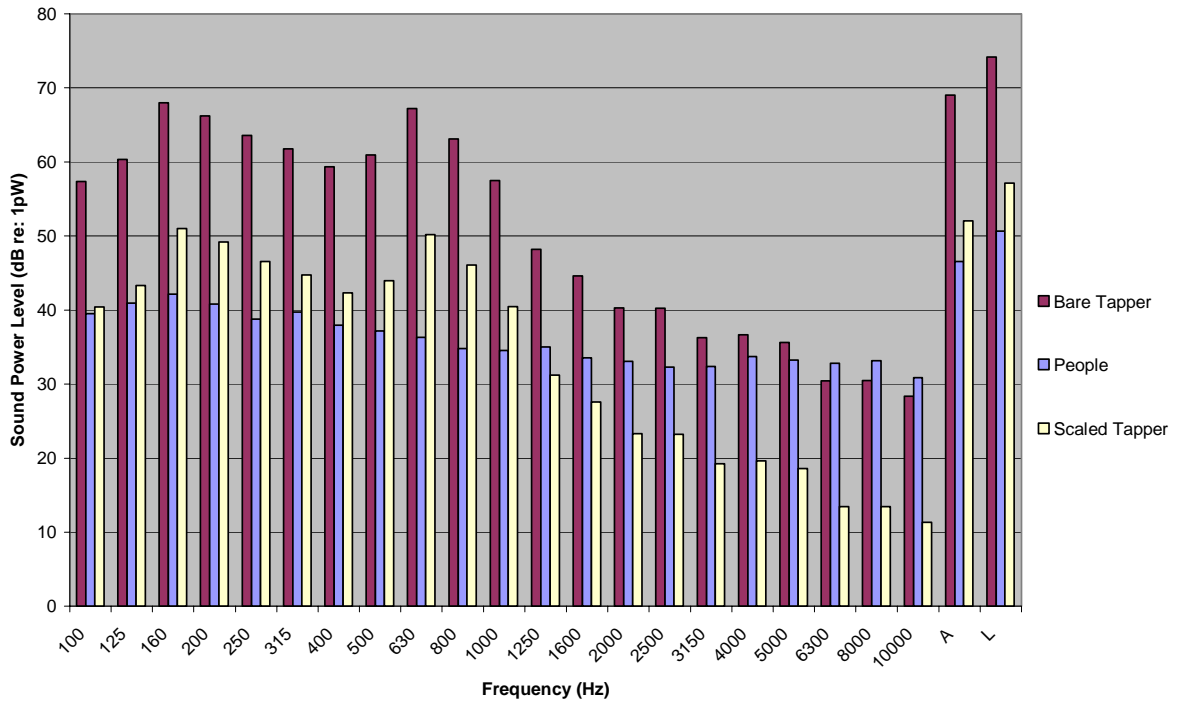


Figure 33: Men's Rubber Sole on Carpet on Concrete



Conclusion

This study examined the effect of footfall noise on several different flooring types. Eleven different floor profiles were used, and men's and women's sneakers, rubber-soled shoes, and leather-soled shoes were utilized. Several criteria were examined: the characteristics of the shoes and floors, the sound power level comparison between similar floors, and the comparability between human walking spectra and the tapping machine spectra, both with and without shoes. The data for individual floors by shoe are presented in Appendix A. Please note that all funds expended for this project were made in accordance with the budget submitted under the original grant proposal.

95% confidence intervals were calculated for each of the human spectra. Subject-to-subject variations were due to differences in gait, stride length, step impact, and stride rate. There was some variation in the size of the confidence intervals between bands, as they depended on sample size, average, and standard deviation. For the hard floors in particular, the confidence intervals were relatively small; i.e., the largest confidence intervals for leather-soled shoes on oak floor span a range of +/- 2 dB.

It was determined that placing carpet directly on bare concrete reduced the overall sound power level by as much as 15 dBA for the women's leather sole. Note that carpet on concrete also produced the lowest overall sound power spectrum of all the floors studied. Adding carpet to a wooden sub-floor reduced the overall sound power level up to 29 dBA for the women's leather-soled shoe. The overall sound power levels were independent of sheet vinyl thickness. Also, for the women's leather sole shoe, the maximum attenuation of adding sheet vinyl to the sub-floor was 7 dBA. Likewise, the addition of 1/4" rubber padding under wool carpet provided 9 dBA of attenuation.

Sound power level spectra for both shoed and bare tapping machines were determined. Constant correction factors (in dB) were applied to these spectra to simulate human footfalls. The constant correction factors applied to tapping machine data with hard shoes on hard floor surfaces accurately reproduced the human spectra. However, application of a suitable constant correction factor is heavily dependent upon both the shoe and floor, and the correction factor found was unique for each of the hard shoes on hard floors. All the shoed tapping machine spectra produced poor correlation with human spectra on soft floor surfaces. The bare tapping machine produced highly tonal spectra, unlike any produced by humans or the shoed tapping machine. These data were also a poor simulator of human footfall spectra. Utilizing a constant correction factor in conjunction with a particular slope may produce a stronger correlation between human data and the shoed tapping machine simulation.

In summary, a core set of human footfall data has been quantified for a variety of floor and shoe types, producing a total of 143 spectra. These sound power spectra can be used to generate reverberant sound pressure level spectra for various applications. As an initial study, 11 floors and 3 types of shoes were investigated, chosen to offer a cross-section of typical applications. Future studies could include other floor constructions, such as wood sub-floors over various air gaps. Also, the concrete base used for this study was comprised of 6 individual slabs for logistical purposes, but a continuous slab could potentially yield different results. Also, the tapping machine was placed in one location on the floor for each test. Future tests could examine whether location of the tapping machine yields different results.

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Our Test Subjects

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University of Hartford Acoustics Laboratory

Spring 2007 Footfall Noise Characterization

Sponsor: Paul S. Veneklasen Research Foundation

Color Key

7 subjects	no fill (white)
6 subjects	blue
5 subjects	green
4 subjects	yellow

Sound Power Levels of Human Footfall Sounds (dB, re: 1 picoWatt)

Floor Profile

Shoe Type

(1) Concrete	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
	Men's Sneaker	42.2	43.8	47.3	47.9	47.8	48.8	47.7	45.7	43.4	41.8	40.3	39.5	37.9	37.3	35.8	34.7	34.7	34.5	34.1	36.7	34.8	52.1	56.9
	95% Confidence	44.4	46.1	49.8	50.3	49.8	50.7	49.9	48.0	45.6	44.5	43.6	42.8	41.0	40.4	38.7	37.2	36.6	36.5	35.9	38.2	36.2	54.3	58.9
	Men's Rubber	40.2	41.7	44.4	44.7	43.7	45.7	47.4	46.5	43.8	41.1	39.8	39.9	38.2	36.4	34.9	34.4	34.4	34.4	34.3	36.4	34.5	51.6	55.3
	95% Confidence	42.4	43.8	46.4	46.7	45.7	47.7	49.3	48.3	45.3	42.7	41.9	42.4	41.5	39.2	37.6	37.0	36.6	36.4	36.3	38.4	36.4	53.4	57.1
	Men's Leather	42.8	44.7	48.0	48.6	46.5	48.0	49.3	48.7	45.2	43.2	42.2	41.2	39.4	37.6	36.0	35.4	35.4	35.6	35.7	37.3	34.9	53.8	58.3
	95% Confidence	46.4	47.6	50.8	52.2	54.8	58.1	57.9	56.7	55.4	53.9	50.6	49.2	46.4	44.6	42.7	40.1	39.4	39.1	39.1	41.6	40.4	61.4	65.1
	Women's Sneaker	36.5	38.0	38.9	39.4	38.9	40.4	40.9	41.7	41.5	40.6	38.6	37.4	36.2	36.6	36.1	36.1	36.1	35.5	35.0	37.2	35.3	49.6	51.7
	95% Confidence	38.2	40.0	41.1	41.7	41.5	43.2	44.1	45.0	45.0	44.2	42.1	40.3	39.0	39.2	38.9	39.0	38.7	38.1	37.6	39.6	37.5	52.5	54.5
	Women's Rubber	38.9	40.0	41.2	42.2	42.3	43.4	42.5	41.0	39.3	38.0	37.3	36.6	35.4	35.6	34.9	35.0	34.9	34.8	34.8	37.5	36.0	49.2	52.6
	95% Confidence	41.1	42.2	44.5	46.9	48.7	50.0	49.1	47.2	45.2	43.7	42.7	41.7	40.0	40.6	39.7	39.4	38.5	38.3	37.9	40.2	38.5	54.2	57.8
	Women's Leather	37.4	39.1	40.5	42.3	44.4	49.2	53.1	56.2	56.6	55.0	54.3	52.8	48.2	46.6	44.2	41.4	40.4	39.1	38.7	40.6	38.2	62.1	63.5
	95% Confidence	39.6	41.0	43.3	44.9	47.5	52.6	56.6	59.3	60.1	58.9	57.8	56.5	52.2	51.0	48.3	46.1	45.2	43.6	43.0	44.6	41.9	65.6	67.0
(2) Sub-floor	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
	Men's Sneaker	48.9	49.5	52.9	54.6	56.0	57.6	57.0	56.7	55.5	53.5	51.8	49.4	46.0	43.5	40.7	39.0	37.7	36.5	35.8	38.4	37.1	61.7	65.6
	95% Confidence	50.8	51.6	55.3	57.2	58.9	61.1	60.5	60.4	59.2	57.0	55.4	52.7	49.3	46.7	43.7	41.4	39.4	38.0	37.3	40.1	39.2	64.9	68.7
	Men's Rubber	48.5	48.5	50.7	51.0	50.9	52.5	54.1	55.8	55.6	55.2	53.7	51.3	47.6	44.0	40.9	39.1	37.7	36.3	36.2	38.1	36.0	61.6	64.1
	95% Confidence	50.1	50.4	52.4	53.2	53.2	54.8	56.4	58.4	58.6	58.5	57.2	54.7	51.0	47.3	44.0	41.6	39.5	37.9	37.8	39.4	37.1	64.5	66.8
	Men's Leather	50.0	50.2	54.3	56.7	59.5	63.1	64.0	64.7	63.5	61.5	59.2	56.0	52.3	48.2	44.4	41.5	38.9	36.9	35.6	37.9	36.4	68.7	71.8
	95% Confidence	51.2	52.0	56.5	58.9	61.6	65.4	66.0	66.6	65.7	63.9	61.5	58.1	54.1	50.2	46.6	43.6	40.5	38.3	36.7	39.0	37.5	70.6	73.6
	Women's Sneaker	49.2	48.9	50.1	51.9	52.4	54.2	54.4	55.6	55.1	54.9	54.0	51.9	48.7	46.6	44.7	43.4	41.1	39.6	38.3	39.9	37.8	62.0	64.5
	95% Confidence	51.3	51.4	52.7	55.1	55.8	57.9	58.3	60.0	59.6	59.5	58.9	56.5	52.5	49.8	48.3	47.2	44.3	42.8	41.0	42.2	39.8	66.1	68.3
	Women's Rubber	49.3	48.3	49.9	52.0	52.5	54.0	54.0	54.9	54.0	52.9	51.6	48.8	45.1	42.3	39.6	38.1	36.8	35.9	35.4	37.8	36.4	60.1	63.4
	95% Confidence	51.0	50.7	52.4	54.8	55.6	57.5	57.4	58.5	57.2	56.3	55.3	52.4	48.3	45.0	41.8	40.3	39.0	38.0	37.5	39.8	38.4	63.3	66.5
	Women's Leather	53.5	52.2	56.3	59.7	62.6	67.7	70.2	71.5	70.5	69.3	68.1	65.8	61.3	57.1	53.6	50.7	48.2	45.7	43.9	44.8	41.7	76.1	78.3
	95% Confidence	66.3	61.8	65.3	68.4	71.7	76.3	79.2	80.3	79.1	78.2	77.0	74.3	70.0	66.2	62.4	59.6	56.7	54.9	53.0	53.3	49.9	84.8	87.0

All Amplitudes are Sound Power Level (dB, re: 1 picoWatt)

7 subjects: no fill; 6 subjects: blue; 5 subjects: green; 4 subjects: yellow

Appendix A1: Averaged Human Subjects Data

(3) Carpet/Concrete	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
	Men's Sneaker	40.3	41.6	43.3	41.8	39.2	38.9	37.8	37.8	36.4	34.6	34.5	36.1	34.4	33.9	33.1	33.0	33.2	32.7	32.3	34.7	33.5	46.9	51.3
	95% Confidence	43.6	44.9	47.4	46.2	44.0	43.3	42.3	41.3	39.1	36.5	35.9	38.5	36.0	35.2	34.4	34.3	34.5	34.1	33.8	36.2	34.8	49.1	54.5
	Men's Rubber	39.5	40.9	42.2	40.8	38.7	39.7	38.0	37.1	36.3	34.8	34.5	35.0	33.5	33.1	32.3	32.4	33.7	33.3	32.8	35.1	33.9	46.5	50.7
	95% Confidence	42.6	43.9	45.9	44.7	42.4	43.2	40.5	39.1	38.2	36.6	35.8	36.2	34.7	34.2	33.2	33.3	35.3	34.8	34.5	36.8	35.5	48.1	53.3
	Men's Leather	41.5	42.4	44.6	45.0	44.1	43.3	39.9	38.0	36.8	35.0	34.5	34.8	33.6	33.5	33.0	33.0	33.6	33.3	32.9	35.3	34.0	47.7	53.1
	95% Confidence	45.5	46.2	48.8	49.8	49.8	49.3	45.5	42.3	41.1	38.7	37.7	37.6	36.0	35.6	35.1	35.2	35.9	35.7	35.2	37.5	36.4	51.2	57.4
	Women's Sneaker	36.3	37.4	38.1	37.9	34.9	36.4	35.5	35.8	35.4	34.6	34.6	34.8	33.9	33.9	32.6	32.2	31.8	31.2	30.9	33.4	32.2	45.5	48.0
	95% Confidence	40.2	42.2	41.9	42.5	40.1	41.2	39.5	39.1	38.6	37.6	37.2	37.1	36.0	36.0	34.8	34.5	34.1	33.7	33.5	35.9	34.7	48.2	51.4
	Women's Rubber	39.3	39.9	39.6	39.6	38.3	39.0	37.2	36.6	36.0	35.0	34.9	34.4	33.0	32.6	31.7	31.6	31.6	31.5	31.4	34.0	32.9	46.2	49.9
	95% Confidence	42.9	44.4	44.9	45.9	45.2	45.3	42.5	40.6	39.9	39.0	38.3	37.4	35.6	35.2	34.2	33.9	33.9	33.7	33.6	36.1	34.8	49.4	54.4
	Women's Leather	36.9	39.0	38.9	38.9	37.4	38.7	38.3	38.4	36.9	35.3	34.2	33.9	32.8	33.0	32.6	32.7	32.7	32.5	32.6	35.2	33.9	46.8	49.8
	95% Confidence	39.6	42.1	43.4	44.3	43.1	44.6	44.8	44.5	42.5	40.2	38.1	37.4	36.1	36.0	35.2	35.2	35.0	35.0	37.5	35.9	50.7	54.2	
(4) Carpet/Sub-floor	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
	Men's Sneaker	44.9	45.0	47.8	47.2	48.0	49.2	47.2	48.5	47.7	45.4	43.2	41.1	38.5	36.3	34.8	34.2	34.1	33.6	33.1	35.6	34.1	53.7	58.0
	95% Confidence	48.6	48.4	51.1	51.4	51.7	53.3	51.9	53.4	52.8	50.7	48.1	45.2	41.7	38.7	36.7	36.0	35.7	35.0	34.4	36.8	35.3	58.0	62.1
	Men's Rubber	43.5	43.8	46.6	46.5	47.6	48.8	46.9	48.3	47.0	44.9	42.6	40.6	37.9	35.9	34.0	33.4	33.6	33.2	32.6	35.1	33.6	53.3	57.4
	95% Confidence	47.0	47.2	50.1	50.5	52.1	53.3	51.7	53.2	52.3	50.4	47.8	45.0	41.3	38.6	36.1	35.0	35.2	34.7	33.8	36.4	34.9	57.7	61.8
	Men's Leather	46.4	47.0	49.5	49.9	50.2	50.9	48.3	48.2	46.9	44.8	43.6	41.4	38.6	37.0	35.8	35.1	34.9	34.3	33.7	36.4	34.9	54.4	59.3
	95% Confidence	50.4	51.4	54.7	55.6	56.3	57.4	54.6	54.1	52.8	50.5	49.1	45.9	41.8	39.5	38.5	37.7	37.2	36.2	35.7	38.3	36.4	59.3	64.6
	Women's Sneaker	41.1	41.9	41.6	41.2	41.4	42.7	41.3	43.0	42.4	40.6	39.9	38.8	37.2	35.9	34.2	33.1	32.6	32.4	32.2	34.8	33.4	50.0	53.1
	95% Confidence	45.7	46.0	47.4	47.1	47.4	48.9	47.3	50.1	49.6	46.9	45.5	44.2	41.5	39.3	37.0	35.2	34.5	34.3	34.1	36.9	35.7	55.4	58.7
	Women's Rubber	43.6	43.3	44.9	44.6	44.7	46.2	44.4	46.2	44.9	43.1	41.8	39.8	37.2	35.3	33.7	32.6	32.6	32.5	32.3	35.0	33.6	51.8	55.5
	95% Confidence	48.4	47.6	50.5	50.9	51.1	53.1	50.9	53.1	51.7	49.4	47.5	44.6	41.3	38.4	36.1	34.4	34.2	34.2	34.0	36.8	35.6	57.2	61.3
	Women's Leather	43.4	43.5	44.7	45.3	45.8	46.6	45.3	46.0	44.5	42.4	40.6	38.4	36.4	35.3	34.5	34.3	34.1	34.0	33.9	36.6	35.1	51.8	55.8
	95% Confidence	47.5	47.5	50.4	51.6	52.3	53.5	51.4	51.9	49.5	46.6	43.9	41.2	38.8	37.6	36.7	36.4	36.4	36.4	36.3	39.1	37.7	56.0	61.0
(5) Wool	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
	Men's Sneaker	46.2	45.7	46.9	47.0	46.8	48.2	48.2	49.1	48.7	47.7	47.8	46.6	44.2	42.3	39.5	38.1	37.1	36.2	35.5	37.9	35.4	56.1	58.9
	95% Confidence	49.1	48.7	49.6	50.1	50.2	51.8	51.9	52.9	52.1	51.1	51.2	50.1	47.6	45.5	42.5	40.8	39.4	38.2	37.2	40.6	37.1	59.4	62.1
	Men's Rubber	44.4	44.0	45.3	45.4	45.8	47.4	47.5	48.2	48.0	47.0	47.1	46.2	44.0	41.9	39.2	37.6	36.6	35.6	34.9	37.7	34.7	55.4	58.0
	95% Confidence	48.4	48.3	49.9	50.1	50.1	51.7	51.3	51.7	51.5	50.5	50.7	50.1	48.0	45.9	43.0	40.8	39.2	37.7	37.0	41.4	36.5	59.1	61.8
	Men's Leather	46.6	46.2	48.6	48.5	48.6	49.5	48.4	48.7	48.9	47.9	48.0	47.1	44.5	42.4	39.7	38.4	37.5	36.7	36.1	38.6	35.5	56.4	59.6
	95% Confidence	50.7	50.4	53.4	53.5	53.9	54.4	53.0	53.1	51.9	51.9	50.9	48.0	45.9	43.1	41.4	40.0	38.9	38.2	41.4	37.4	60.3	63.8	
	Women's Sneaker	42.3	41.2	44.1	44.9	45.4	47.0	47.1	47.7	47.8	46.6	46.5	45.8	43.6	42.1	39.5	38.1	36.8	36.1	35.6	37.3	34.9	55.2	57.5
	95% Confidence	45.8	44.3	47.8	49.0	49.8	51.0	51.2	51.9	51.8	50.3	49.6	49.0	46.7	44.9	42.2	40.4	38.4	37.3	36.8	38.5	36.2	58.4	61.1
	Women's Rubber	43.1	42.0	43.9	44.7	44.4	45.6	45.6	46.5	46.8	45.6	46.0	45.4	43.1	41.1	38.2	36.5	35.3	34.7	34.1	36.3	34.5	54.3	56.7
	95% Confidence	46.5	45.2	47.9	49.4	48.9	49.8	49.2	50.4	51.0	49.5	50.0	49.3	46.9	44.3	41.2	38.9	37.0	36.3	35.8	38.2	36.6	57.9	60.4
	Women's Leather	43.9	43.6	46.1	47.9	48.6	50.7	49.9	49.9	49.7	48.2	47.5	46.0	43.1	41.1	38.5	37.4	36.9	36.6	36.3	38.0	35.4	56.6	59.7
	95% Confidence	46.9	46.4	50.2	53.1	54.1	56.1	54.7	53.3	52.9	51.1	50.5	49.3	46.4	44.4	41.6	40.2	39.2	38.9	38.4	39.9	37.3	59.9	63.5

All Amplitudes are Sound Power Level (dB, re: 1 picoWatt)

7 subjects: no fill; 6 subjects: blue; 5 subjects: green; 4 subjects: yellow

Appendix A1: Averaged Human Subjects Data

(6) Wool/Pad	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
Men's Sneaker		41.5	42.5	42.3	42.2	43.1	44.7	44.7	46.5	46.1	44.7	44.4	43.5	41.6	40.2	37.9	37.4	37.0	36.3	35.5	37.8	35.8	53.7	56.1
95% Confidence		44.3	45.1	44.8	44.8	45.8	47.6	47.9	49.9	49.7	48.1	48.3	47.4	45.8	44.2	41.4	40.8	40.2	39.6	38.9	40.9	38.8	57.0	58.9
Men's Rubber		40.4	41.8	41.5	41.6	42.0	43.7	43.6	44.4	43.7	42.7	41.4	40.3	38.0	36.3	34.4	34.1	34.4	34.9	33.6	36.2	35.5	51.2	54.1
95% Confidence		44.0	45.3	44.6	44.8	45.6	47.2	47.4	48.4	47.7	47.1	45.5	44.0	41.2	39.2	37.0	36.7	37.3	38.6	36.3	38.8	39.0	54.7	57.6
Men's Leather		42.0	44.0	42.5	42.7	43.5	45.0	44.8	46.0	45.9	44.6	42.6	40.8	38.6	37.1	35.2	34.7	34.6	34.0	33.5	36.1	34.6	52.5	55.4
95% Confidence		46.7	48.5	46.8	47.0	48.1	49.9	50.0	51.3	51.1	49.7	47.0	44.3	41.5	39.5	37.0	36.3	36.2	35.7	35.3	37.8	36.4	56.4	59.8
Women's Sneaker		38.7	39.6	37.7	37.6	38.0	39.2	39.1	40.0	40.2	39.2	39.1	38.7	37.3	36.8	34.8	34.0	33.7	33.2	32.9	35.5	34.1	48.8	51.0
95% Confidence		42.6	44.8	41.2	41.3	41.8	43.1	42.9	43.9	44.2	42.9	42.1	41.3	40.0	39.5	37.1	36.5	36.2	35.5	35.2	37.9	36.3	51.8	54.1
Women's Rubber		38.9	41.0	38.4	39.0	39.1	40.4	40.2	40.7	40.1	38.6	38.3	37.7	35.9	34.9	33.0	32.2	32.4	32.1	32.0	34.7	33.2	48.2	50.9
95% Confidence		43.0	46.0	42.1	42.7	42.8	44.6	44.2	45.1	44.7	42.3	41.4	40.4	38.6	37.2	35.0	34.2	34.3	33.9	33.8	36.5	35.0	51.3	54.4
Women's Leather		39.9	39.7	39.1	39.5	39.5	40.3	41.3	41.8	41.1	39.6	39.0	38.1	36.4	35.6	33.9	33.4	33.4	33.2	33.0	35.6	33.9	49.1	51.8
95% Confidence		43.7	43.8	43.8	44.1	43.8	44.4	45.7	45.9	44.8	42.9	42.1	41.4	39.5	38.7	36.6	35.9	35.6	35.4	35.0	37.4	35.5	52.1	55.2
(7) Thin Vinyl	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
Men's Sneaker		47.5	48.0	51.4	52.8	54.0	55.8	54.2	53.1	51.4	48.9	46.4	45.4	41.7	40.1	38.2	36.8	35.6	34.8	35.0	36.4	35.2	58.0	62.8
95% Confidence		49.6	50.3	53.8	55.0	56.1	57.7	56.3	55.6	53.7	51.1	48.8	46.8	43.2	41.7	39.2	37.9	36.7	35.8	36.1	37.6	36.7	60.0	64.8
Men's Rubber		45.7	45.6	48.5	48.9	48.8	50.8	51.7	52.7	52.3	51.1	49.8	48.0	44.3	41.5	39.5	38.2	37.1	36.7	36.0	37.4	35.6	58.3	61.2
95% Confidence		47.9	47.6	50.8	51.3	51.0	53.3	53.9	55.0	54.3	53.2	52.1	50.2	46.8	44.0	42.0	40.8	39.8	39.5	38.5	39.8	37.8	60.5	63.3
Men's Leather		49.7	49.7	53.7	55.6	58.5	62.1	62.1	62.4	61.4	59.3	56.9	53.8	49.3	45.8	42.4	40.1	37.5	36.0	35.5	37.2	35.9	66.6	69.9
95% Confidence		51.7	52.2	56.4	58.7	61.6	65.5	65.4	65.4	64.3	62.1	59.9	57.2	52.8	49.0	45.3	42.7	39.5	37.6	37.0	38.6	37.3	69.5	72.9
Women's Sneaker		43.8	43.7	46.0	46.8	47.1	49.3	48.8	49.4	49.2	48.0	46.6	45.9	42.5	41.0	39.1	37.9	36.9	36.2	35.5	36.9	35.1	56.0	58.9
95% Confidence		47.5	47.6	50.2	51.6	52.1	54.4	54.0	54.3	54.0	53.1	52.2	51.1	47.8	45.9	43.4	41.7	40.7	40.0	38.9	39.5	37.5	60.7	63.5
Women's Rubber		45.1	44.4	46.9	48.3	49.4	51.0	50.4	50.6	49.5	47.8	46.1	44.5	40.7	39.0	37.2	36.0	35.2	35.1	34.7	36.6	35.0	55.9	59.6
95% Confidence		48.4	47.6	50.3	52.1	53.7	55.6	55.1	55.8	54.2	52.0	50.4	48.0	43.9	42.3	40.4	38.8	37.7	37.6	36.2	37.8	36.0	60.0	63.8
Women's Leather		44.2	45.0	49.4	52.5	55.8	61.3	62.7	64.0	63.4	62.2	61.3	58.2	53.3	49.6	46.2	44.1	42.1	39.8	38.1	38.9	36.8	68.9	71.1
95% Confidence		47.0	47.7	52.4	55.4	59.1	64.5	65.5	66.3	66.0	64.8	63.7	60.7	56.1	52.8	49.8	48.3	46.1	43.5	40.9	41.4	39.1	71.4	73.7
(8) Medium Vinyl	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
Men's Sneaker		47.6	49.0	51.8	52.7	54.0	55.8	53.9	52.9	51.0	48.6	46.1	43.2	39.9	38.0	35.6	34.7	34.0	33.1	32.7	34.7	32.7	57.6	62.7
95% Confidence		50.0	51.6	54.1	55.0	56.1	57.9	56.2	55.5	53.8	51.5	48.8	45.9	42.7	41.0	38.5	37.3	36.3	35.0	34.4	35.9	33.7	60.0	65.0
Men's Rubber		46.4	47.5	49.6	49.7	50.1	51.6	51.9	53.1	52.8	51.9	50.9	48.8	45.0	41.7	38.8	37.5	36.1	35.4	34.7	36.5	34.4	58.9	61.9
95% Confidence		48.7	50.1	52.3	52.7	52.8	54.3	54.9	55.8	55.5	54.9	53.8	51.8	48.3	45.1	41.8	40.4	38.9	38.4	37.6	39.2	36.8	61.7	64.6
Men's Leather		50.2	51.7	54.8	56.8	59.8	63.2	62.5	62.8	62.0	59.6	57.3	54.2	50.1	46.2	42.4	39.8	37.1	35.0	34.1	36.0	34.4	67.1	70.6
95% Confidence		52.2	53.9	57.0	59.3	61.9	65.7	64.8	64.7	63.9	61.2	59.1	56.5	52.8	49.1	45.5	42.7	38.8	36.2	35.3	36.9	35.3	68.9	72.5
Women's Sneaker		43.5	44.3	45.6	46.5	47.2	48.7	47.4	48.0	47.3	46.1	44.4	42.6	40.3	39.0	37.2	36.3	35.5	34.8	33.8	35.6	33.2	54.1	57.6
95% Confidence		46.2	47.4	48.8	50.1	51.0	52.7	51.4	52.2	51.6	50.4	48.7	47.2	44.8	43.3	40.8	39.3	38.6	37.5	36.2	37.7	35.1	58.1	61.4
Women's Rubber		45.8	46.5	47.8	48.9	50.0	51.1	50.1	50.4	49.3	47.5	45.7	43.2	39.5	37.8	36.7	36.4	35.2	34.6	34.1	36.4	34.3	55.5	59.7
95% Confidence		49.1	49.9	51.4	53.0	55.0	56.5	55.5	56.0	54.8	53.1	51.1	48.6	44.7	42.8	42.4	42.2	40.1	38.6	37.1	38.5	35.9	60.8	64.6
Women's Leather		44.4	45.9	49.5	52.5	56.0	61.2	61.9	63.4	63.6	62.4	61.6	59.1	54.2	50.1	46.8	44.2	41.9	39.5	37.4	38.5	36.0	69.0	71.0
95% Confidence		47.3	48.6	52.6	55.7	59.5	64.7	64.8	65.9	66.4	65.2	64.4	62.0	57.4	53.7	50.4	48.2	45.7	43.0	40.7	41.1	38.0	71.8	73.9

All Amplitudes are Sound Power Level (dB, re: 1 picoWatt)

7 subjects: no fill; 6 subjects: blue; 5 subjects: green; 4 subjects: yellow

Appendix A1: Averaged Human Subjects Data

(9) Thick Vinyl	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
Men's Sneaker		48.2	48.9	51.8	53.8	54.9	56.5	54.9	54.4	52.6	50.6	48.1	44.9	41.8	39.8	37.0	35.1	33.7	32.7	31.8	34.0	32.2	59.0	63.7
95% Confidence		50.9	51.6	54.4	56.4	57.3	59.3	57.8	57.6	55.8	54.1	52.1	48.9	45.8	43.8	40.6	38.1	36.1	34.7	33.7	35.8	33.9	62.0	66.5
Men's Rubber		46.6	47.2	49.3	50.1	50.0	52.2	52.4	54.2	53.7	53.1	51.7	49.3	45.0	41.0	37.6	35.8	34.0	32.7	32.0	34.2	32.3	59.5	62.4
95% Confidence		49.1	49.3	51.6	52.6	52.7	54.8	54.8	56.3	56.2	55.9	54.6	52.1	48.0	44.0	40.4	38.5	36.1	34.6	33.7	35.9	34.0	62.1	64.9
Men's Leather		50.5	51.0	54.4	57.3	60.1	63.8	63.3	64.0	63.0	60.9	58.6	55.3	51.8	47.7	43.7	39.9	36.6	34.5	33.4	35.4	33.8	68.2	71.5
95% Confidence		53.0	53.5	57.4	60.2	63.7	67.6	66.9	67.1	65.8	63.5	61.2	58.2	54.7	50.3	46.5	42.3	38.7	36.7	35.6	37.6	35.8	71.0	74.6
Women's Sneaker		44.0	43.9	43.6	45.2	45.1	47.4	46.3	46.8	46.0	45.5	44.3	42.0	39.2	38.5	37.5	36.8	35.9	34.9	33.8	35.9	34.2	53.5	56.6
95% Confidence		46.4	46.7	47.5	49.4	49.3	52.2	51.6	52.3	51.4	51.0	50.0	46.9	43.1	42.5	42.2	41.2	39.9	38.9	37.3	39.6	37.7	58.3	61.3
Women's Rubber		44.7	45.4	45.8	48.1	48.3	50.0	48.8	49.0	47.7	46.3	44.7	41.9	38.6	37.3	36.0	35.5	35.0	34.4	33.5	35.8	34.1	54.4	58.4
95% Confidence		48.3	48.3	49.9	52.6	53.5	55.7	54.4	54.9	53.4	51.8	50.5	47.5	44.0	42.5	41.3	40.6	39.7	38.4	36.5	38.4	36.4	59.8	63.6
Women's Leather		42.6	44.2	47.5	51.6	54.8	60.5	61.2	63.1	62.9	61.7	61.5	59.1	54.3	50.4	46.2	43.0	40.4	37.9	36.2	37.4	34.8	68.6	70.5
95% Confidence		45.5	45.9	50.6	55.2	58.5	64.2	64.5	66.1	66.2	65.0	64.7	62.3	58.0	54.5	50.6	47.6	44.9	42.3	40.0	40.6	37.7	71.9	73.8
(10) Oak Flooring	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
Men's Sneaker		44.9	46.5	50.2	51.7	52.3	53.6	51.9	50.7	49.7	48.8	48.4	47.6	45.8	44.9	43.2	42.4	41.5	40.9	39.5	42.0	39.8	58.4	61.8
95% Confidence		47.4	49.2	53.4	54.9	55.3	56.6	55.3	53.7	52.2	50.8	49.8	48.9	46.8	45.9	44.1	43.4	42.8	41.8	40.4	43.1	40.7	60.1	64.3
Men's Rubber		43.3	44.4	47.6	48.0	47.5	49.5	50.6	50.8	50.3	50.0	49.9	48.7	46.2	44.7	43.1	42.7	42.1	41.5	40.0	42.6	40.3	58.4	60.6
95% Confidence		45.4	46.4	50.2	50.9	50.2	52.1	52.8	52.9	52.3	52.0	52.1	50.8	48.0	46.4	44.7	44.1	44.0	43.8	42.0	44.4	42.0	60.2	62.5
Men's Leather		47.2	48.6	52.8	55.8	58.2	61.1	61.1	61.6	61.1	60.0	59.1	57.3	54.6	51.8	48.3	46.2	44.0	42.8	41.1	43.5	41.3	67.5	70.0
95% Confidence		49.7	50.9	55.6	59.0	61.8	64.9	64.3	64.7	64.0	63.0	62.0	60.4	57.8	54.9	51.1	48.6	45.8	44.4	42.3	44.6	42.3	70.4	73.0
Women's Sneaker		40.2	41.0	42.8	44.2	44.0	45.7	45.5	45.9	46.9	47.2	47.3	46.8	44.9	43.8	42.2	41.3	40.2	39.7	38.3	40.8	38.6	56.1	57.6
95% Confidence		43.4	43.9	47.0	49.2	49.4	51.1	50.8	50.1	50.6	50.5	50.1	49.2	47.0	45.6	44.0	42.9	41.9	42.0	40.2	42.6	40.4	58.8	61.0
Women's Rubber		42.6	42.6	45.0	46.4	46.5	47.8	46.6	46.8	47.3	47.5	47.8	47.0	44.9	43.8	42.4	41.9	40.9	40.3	38.9	41.6	39.3	56.6	58.6
95% Confidence		45.5	45.6	48.1	50.4	51.3	52.7	51.4	51.0	50.3	49.8	49.7	48.6	46.5	45.5	43.8	43.1	42.2	42.5	40.5	43.3	40.9	58.6	61.4
Women's Leather		39.4	41.2	45.1	48.7	51.1	55.7	57.1	59.3	60.7	61.2	62.8	61.5	57.5	54.3	50.4	47.2	45.0	42.8	40.9	42.8	40.6	68.8	69.5
95% Confidence		41.4	43.5	48.7	52.2	54.9	59.2	60.4	62.6	64.0	64.6	66.2	65.1	61.2	58.2	54.5	51.4	48.6	45.8	43.6	45.1	42.6	72.2	73.0
(11) Ceramic Tile	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
Men's Sneaker		47.2	48.4	51.4	52.9	53.3	54.1	51.7	50.8	49.4	47.6	45.6	43.2	40.4	38.3	35.6	34.5	34.6	33.5	32.7	35.2	33.7	56.4	61.6
95% Confidence		49.4	50.4	53.5	55.5	55.6	56.2	53.7	53.0	52.1	50.2	48.3	46.1	43.5	41.7	38.2	36.5	36.3	35.2	34.3	36.6	35.2	58.6	63.8
Men's Rubber		46.1	46.5	48.4	48.8	47.3	48.8	49.8	50.7	50.5	49.7	48.6	46.4	42.5	39.4	36.9	35.5	35.6	34.2	33.3	35.9	33.9	56.7	59.8
95% Confidence		48.7	49.0	51.0	51.6	50.0	51.1	52.0	52.4	52.5	52.1	51.4	49.3	45.3	42.5	40.1	38.8	40.0	37.9	36.9	39.3	37.0	59.1	62.2
Men's Leather		49.0	50.3	53.7	56.7	59.2	62.5	62.2	63.5	63.6	62.4	60.2	57.7	53.8	49.1	43.8	40.1	38.3	37.4	37.0	39.9	38.5	68.8	71.5
95% Confidence		50.4	51.7	55.7	59.1	62.3	66.0	65.0	65.6	65.1	63.9	61.4	59.0	55.1	50.2	44.7	41.3	39.5	39.1	39.0	42.0	41.0	70.4	73.5
Women's Sneaker		43.1	43.8	45.3	45.8	44.3	45.4	44.6	45.1	45.3	44.5	42.9	40.8	38.0	36.6	35.3	34.8	34.1	33.4	32.8	34.8	33.0	52.1	55.7
95% Confidence		46.0	47.7	49.5	50.1	48.5	50.0	48.9	49.1	49.4	48.8	47.3	45.0	41.3	39.2	38.0	37.3	36.2	35.2	34.3	36.1	34.2	55.8	59.6
Women's Rubber		44.3	45.4	46.4	47.7	47.0	47.6	46.3	46.1	45.3	44.5	43.3	41.1	38.0	36.3	34.3	34.1	33.6	32.9	32.7	35.6	34.2	52.6	56.9
95% Confidence		48.4	49.5	51.3	52.9	52.5	53.4	51.7	51.5	50.3	49.4	47.9	44.9	41.4	39.4	37.1	36.8	35.8	34.9	34.7	37.6	36.3	57.1	61.8
Women's Leather		42.2	44.3	46.6	49.8	52.8	56.8	58.3	61.7	63.6	64.3	66.1	64.5	60.1	56.0	50.1	45.7	42.6	39.7	38.2	39.7	37.5	71.6	72.3
95% Confidence		46.1	47.1	50.3	53.7	56.9	61.0	62.5	65.7	67.9	68.7	69.8	68.1	64.1	60.1	54.7	50.5	47.2	44.0	42.2	43.3	40.9	75.5	76.2

All Amplitudes are Sound Power Level (dB, re: 1 picoWatt)

7 subjects: no fill; 6 subjects: blue; 5 subjects: green; 4 subjects: yellow

Appendix A2: Tapping Machine Data

University of Hartford Acoustics Laboratory

Spring 2007 Footfall Noise Characterization

Sponsor: Paul S. Veneklasen Research Foundation

Color Key

Red bands below background

Sound Power Levels of Tapper Sounds (dB, re: 1 picoWatt)

Floor Profile	Shoe Type on Tapper	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
(1) Concrete	Men's Sneaker	61.0	64.2	69.0	67.4	60.1	58.0	56.0	59.9	54.7	57.5	57.5	50.9	49.2	46.9	46.3	45.4	45.3	43.4	41.2	40.7	34.4	65.4	73.5	
	Men's Rubber	60.9	66.1	73.7	75.7	66.3	63.8	62.4	63.9	55.5	58.1	59.5	49.8	48.1	45.7	43.7	42.1	42.4	43.4	45.3	41.5	34.7	69.6	79.0	
	Men's Leather	59.7	63.6	70.2	69.3	66.6	68.0	68.0	67.8	81.1	78.3	63.4	73.0	57.4	50.5	50.3	53.2	54.1	54.0	54.8	53.8	48.3	82.5	84.3	
	Women's Sneaker	61.2	63.9	68.1	67.9	61.2	57.6	54.9	58.9	52.5	54.7	56.5	48.9	47.4	45.0	45.5	47.0	48.0	47.2	48.3	50.0	40.2	64.9	73.2	
	Women's Rubber	59.9	65.4	70.6	71.7	63.5	59.2	57.7	62.8	54.8	57.6	59.4	51.1	48.4	44.1	44.1	44.7	47.0	49.3	48.0	42.6	37.4	67.4	75.8	
	Women's Leather	58.9	63.8	70.6	68.4	67.5	70.0	70.1	70.5	84.8	82.1	69.9	82.0	67.9	59.2	54.3	51.1	51.7	52.2	50.2	51.7	44.6	87.4	88.5	
	Bare Tapper	58.4	62.1	70.2	71.2	67.6	70.8	71.7	73.9	89.0	85.7	79.4	93.8	83.2	83.4	87.3	86.1	85.9	84.4	81.3	78.5	69.5	98.2	97.8	
	(2) Sub-floor	Men's Sneaker	72.6	70.5	73.7	73.9	72.0	70.7	72.5	72.5	68.9	65.9	62.1	56.8	53.8	51.9	51.0	51.0	49.4	43.6	38.7	36.9	32.2	75.3	81.9
Men's Rubber		73.6	74.5	78.0	77.4	79.5	78.4	78.4	76.8	72.4	69.9	70.5	65.5	60.1	56.5	54.1	55.3	54.1	55.8	54.0	52.3	51.2	80.8	86.9	
Men's Leather		74.1	75.3	78.5	81.4	85.2	87.0	89.2	91.7	87.2	85.0	81.8	77.4	73.0	67.8	64.4	62.1	58.7	57.2	55.2	54.9	50.8	93.1	96.5	
Women's Sneaker		70.0	68.3	70.7	69.4	67.8	68.2	68.2	69.1	66.4	64.0	60.6	53.8	49.7	47.8	48.7	50.5	49.9	49.0	46.0	43.4	35.9	72.3	78.6	
Women's Rubber		72.7	73.1	74.7	74.7	73.1	70.1	70.0	71.6	68.5	64.6	63.4	58.1	52.6	49.4	48.7	47.6	46.8	44.6	40.9	34.9	30.8	74.8	82.2	
Women's Leather		73.9	77.0	79.1	81.6	85.4	89.0	92.4	93.9	92.4	91.7	90.4	87.0	82.9	79.5	74.9	71.8	68.7	68.6	67.0	64.6	60.0	98.1	100.3	
Bare Tapper		70.7	69.9	76.6	80.4	85.2	92.0	94.9	95.2	95.1	94.9	94.7	92.9	89.7	87.5	84.3	80.5	75.9	72.2	68.1	63.9	58.7	101.9	103.4	
(3) Carpet/Concrete		Men's Sneaker	57.1	62.6	67.4	66.4	59.4	56.5	56.6	60.8	55.7	55.7	59.9	52.8	50.5	45.1	44.8	40.3	39.0	36.7	35.2	33.2	28.7	65.6	72.4
	Men's Rubber	57.0	61.3	67.0	66.9	60.8	58.8	56.6	60.0	51.8	54.2	56.5	46.7	44.8	40.2	39.9	36.7	36.8	33.8	28.7	27.5	23.0	64.0	72.1	
	Men's Leather	57.9	61.6	67.5	67.1	63.3	61.4	57.4	57.9	58.0	56.3	56.5	47.1	44.3	40.0	39.9	36.8	36.8	33.4	28.9	28.6	26.8	65.0	72.8	
	Women's Sneaker	56.5	61.9	67.5	67.2	59.8	56.2	55.8	60.4	52.7	52.9	55.9	48.9	46.8	41.4	40.8	38.9	38.4	37.9	37.8	36.4	31.1	64.0	72.2	
	Women's Rubber	58.9	62.5	68.7	68.6	59.0	57.0	56.5	60.3	52.4	55.5	58.0	47.4	45.4	40.4	39.7	37.1	37.3	33.8	29.8	28.3	23.9	64.8	73.3	
	Women's Leather	56.6	60.4	66.8	64.9	61.5	60.1	57.7	60.3	59.3	56.2	55.7	46.6	44.3	39.8	39.8	37.3	37.9	36.8	35.2	35.2	31.9	64.8	71.9	
	Bare Tapper	57.4	60.3	68.0	66.2	63.5	61.7	59.3	61.0	67.2	63.1	57.5	48.2	44.6	40.3	40.2	36.2	36.7	35.6	30.4	30.5	28.4	69.0	74.1	

All Amplitudes are Sound Power Level (dB, re: 1 picoWatt)

Red: band below background

Appendix A2: Tapping Machine Data

(4) Carpet/Sub-floor	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
Men's Sneaker	65.2	65.7	68.6	69.1	67.6	64.9	61.4	63.3	61.8	60.7	58.7	52.5	46.0	40.4	39.9	37.9	37.5	35.2	32.9	33.4	31.3	68.5	75.9	
Men's Rubber	70.0	67.9	72.9	73.1	72.4	70.6	67.9	67.4	67.0	65.1	62.5	58.0	50.5	43.5	40.7	37.9	37.9	35.8	33.0	32.3	29.3	73.2	80.3	
Men's Leather	70.9	68.6	72.1	75.0	75.4	75.9	73.8	72.1	67.8	63.8	61.6	56.4	49.3	43.0	40.9	38.4	37.7	36.1	34.6	34.1	30.3	76.1	82.8	
Women's Sneaker	64.0	63.4	66.9	66.2	63.1	60.8	57.7	60.1	55.7	54.5	55.4	47.5	45.2	41.2	40.6	39.0	37.9	36.5	36.0	35.1	31.4	64.6	72.9	
Women's Rubber	68.6	66.6	68.7	67.8	64.4	64.2	62.1	63.3	61.2	59.4	58.4	50.8	45.9	40.6	40.1	37.6	37.8	36.5	35.6	34.4	30.1	67.8	75.7	
Women's Leather	70.1	69.7	73.9	76.1	77.0	77.4	76.9	76.0	72.4	69.4	66.7	62.6	55.3	47.5	42.5	38.6	38.5	37.1	34.6	33.8	29.1	79.3	84.9	
Bare Tapper	68.9	70.6	74.1	76.9	78.3	79.9	78.8	80.0	76.7	70.9	68.0	63.8	56.2	49.2	43.5	38.6	37.5	35.8	31.2	31.0	28.3	82.0	87.0	
(5) Wool	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
Men's Sneaker	63.2	63.8	67.7	66.9	63.1	59.4	58.4	61.0	59.8	59.1	61.3	60.5	58.1	55.8	53.0	50.3	46.9	43.7	40.8	36.3	30.4	68.9	74.1	
Men's Rubber	61.4	66.3	67.8	69.1	68.4	67.9	64.4	64.1	63.9	62.9	62.7	59.8	56.8	53.9	49.5	46.7	45.1	43.4	41.8	39.2	33.0	71.1	76.7	
Men's Leather	63.9	66.4	70.9	71.0	71.1	73.7	71.5	69.2	67.8	66.6	65.0	62.6	59.6	56.5	53.3	50.5	49.0	47.8	45.5	43.1	37.1	75.2	80.3	
Women's Sneaker	60.3	63.6	66.1	65.7	60.5	60.6	61.6	62.8	61.2	60.5	60.0	57.6	55.4	51.5	48.8	46.1	42.7	40.4	36.6	33.7	27.7	68.2	73.3	
Women's Rubber	61.3	64.4	68.4	68.6	61.9	63.6	65.0	65.4	63.2	62.7	62.2	60.4	58.0	54.6	50.5	48.3	45.2	43.0	40.7	36.9	29.6	70.7	75.6	
Women's Leather	62.8	65.7	69.3	70.9	71.1	73.1	71.4	70.7	69.1	67.1	67.1	64.7	61.0	57.5	53.0	50.3	48.2	45.3	43.1	40.1	34.8	75.9	80.4	
Bare Tapper	67.8	67.3	71.7	71.9	74.1	77.7	79.3	81.5	79.0	73.5	74.3	69.3	66.3	62.9	59.6	58	57.7	55.7	52.9	48.2	39.63	83.7	87	
(6) Wool/Pad	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
Men's Sneaker	54.9	60.7	64.7	62.6	58.5	56.1	55.0	60.1	57.0	55.5	53.2	45.6	43.3	38.9	37.6	35.0	34.7	34.5	33.5	32.7	27.6	63.1	69.9	
Men's Rubber	54.7	60.2	65.5	63.9	60.4	55.9	54.7	59.7	58.5	56.7	53.6	45.7	44.3	39.8	37.2	33.7	33.9	32.3	25.5	24.1	21.1	63.7	70.6	
Men's Leather	56.4	62.2	66.0	65.0	59.8	54.7	53.5	58.2	53.7	53.0	52.4	44.9	42.3	39.0	36.5	33.4	33.2	31.3	25.4	23.7	21.0	62.2	70.8	
Women's Sneaker	54.2	60.6	66.4	63.6	60.1	55.9	55.2	59.7	55.8	54.2	53.5	46.2	43.5	38.7	38.0	35.6	34.6	35.0	34.8	34.5	30.0	63.0	70.7	
Women's Rubber	53.4	61.1	65.1	64.9	60.7	56.8	55.5	59.5	57.3	56.0	53.7	46.2	44.3	39.5	37.5	34.9	34.3	33.7	31.4	31.0	26.5	63.6	70.8	
Women's Leather	54.1	60.5	65.5	64.1	59.2	55.3	54.0	59.1	55.0	53.5	53.6	45.6	43.0	38.6	36.6	33.2	33.4	32.3	25.3	23.7	20.8	62.5	70.2	
Bare Tapper	55.0	60.8	62.9	63.6	60.9	56.1	54.8	59.8	52.8	53.3	54.9	45.7	42.9	38.4	36.3	33.0	32.4	31.5	25.4	23.5	20.7	62.6	69.8	
(7) Thin Vinyl	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
Men's Sneaker	70.5	70.7	73.7	73.0	70.6	71.0	72.2	73.8	73.1	69.4	67.6	64.9	60.1	57.6	55.2	53.4	51.2	48.1	44.5	41.4	36.7	77.6	82.3	
Men's Rubber	67.9	71.0	75.3	78.8	77.8	77.9	76.3	77.3	74.4	71.2	69.2	65.5	60.5	57.1	54.1	51.9	49.1	45.7	45.9	42.3	35.0	80.6	86.0	
Men's Leather	72.3	73.3	76.0	79.5	83.3	86.3	88.3	89.8	86.9	82.6	78.2	72.2	67.1	62.8	59.1	61.2	58.7	56.5	53.8	52.6	47.7	91.4	95.1	
Women's Sneaker	65.4	65.9	68.7	68.8	67.7	69.8	69.4	70.6	69.8	66.7	64.9	61.0	55.6	52.1	49.9	49.8	48.7	47.1	46.9	47.6	39.0	74.5	78.9	
Women's Rubber	71.0	71.0	73.5	74.3	71.7	71.5	71.7	73.9	74.2	70.1	68.1	65.0	59.8	56.9	54.5	53.2	51.6	49.2	47.0	44.4	39.2	78.1	82.8	
Women's Leather	72.4	74.5	75.9	81.0	84.5	87.8	90.6	93.1	91.9	88.7	86.3	82.5	76.5	72.6	66.9	61.7	58.8	57.4	58.8	60.2	55.3	95.9	98.6	
Bare Tapper	66.2	69.8	75.5	79.0	84.7	89.8	91.4	96.5	96.1	93.9	93.5	91.7	87.6	85.1	82.0	79.2	75.1	71.1	67.3	64.8	60.6	101.1	102.7	

All Amplitudes are Sound Power Level (dB, re: 1 picoWatt)

Red: band below background

Appendix A2: Tapping Machine Data

(8) Medium Vinyl	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
	Men's Sneaker	71.4	74.4	73.4	74.3	74.6	74.4	75.0	74.1	74.0	74.9	74.9	71.7	66.3	63.1	60.7	57.7	54.6	52.3	48.1	44.2	39.9	81.4	85.0
Men's Rubber	71.6	76.9	76.7	77.0	78.7	79.4	75.8	74.0	73.2	72.5	71.6	68.5	63.7	60.4	57.7	55.6	52.6	52.1	51.9	49.3	43.1	80.7	86.5	
Men's Leather	72.3	75.7	77.4	80.5	84.3	87.7	87.7	87.3	86.3	83.3	80.0	76.9	72.3	69.2	66.6	62.9	58.7	56.6	54.9	52.6	48.1	91.1	94.8	
Women's Sneaker	70.7	71.3	72.0	70.2	67.4	68.9	67.9	67.2	65.2	64.0	60.6	55.9	52.3	47.7	47.8	47.0	46.9	46.7	45.0	42.3	36.8	71.9	79.2	
Women's Rubber	72.0	74.8	74.9	75.8	73.0	72.4	70.1	71.8	71.9	70.6	70.1	66.9	61.7	57.1	53.8	50.4	49.0	47.8	44.1	42.5	37.7	77.9	83.5	
Women's Leather	71.3	74.8	78.4	81.0	86.3	90.5	91.0	91.3	91.1	90.1	87.7	84.0	79.5	74.6	69.8	65.7	63.3	60.5	58.7	59.6	58.2	96.1	98.8	
Bare Tapper	71.4	75.3	78.2	81.3	86.3	91.2	92.9	94.3	95.5	95.7	95.6	93.2	90.9	87.7	84.4	80.9	76.8	73.2	69.7	67.2	62.6	102.2	103.4	

(9) Thick Vinyl	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
	Men's Sneaker	72.5	70.3	73.2	74.6	71.5	71.6	70.5	72.5	70.7	69.8	68.2	61.8	56.1	54.9	53.3	51.3	48.9	44.6	40.6	37.4	33.6	76.7	82.2
Men's Rubber	76.7	74.0	76.7	78.5	78.6	81.2	78.2	74.2	70.6	70.0	67.7	61.7	57.2	55.3	54.0	51.3	47.9	46.4	44.7	41.0	35.3	80.3	87.1	
Men's Leather	71.6	71.4	75.8	80.9	82.9	86.1	86.0	89.7	87.5	84.3	81.1	76.6	70.1	66.6	63.6	60.1	57.4	55.2	52.5	52.5	50.7	91.8	95.0	
Women's Sneaker	74.6	70.4	70.5	69.8	67.1	70.1	67.4	69.0	68.3	66.2	63.7	60.0	54.3	50.7	47.3	47.3	46.2	46.4	45.4	46.3	37.7	73.5	80.2	
Women's Rubber	76.5	72.8	75.3	77.0	72.7	72.1	69.4	70.6	69.4	68.8	66.9	61.8	56.4	53.3	50.8	49.6	48.2	46.7	44.9	41.8	36.7	76.1	83.5	
Women's Leather	75.3	73.7	76.8	81.8	84.8	90.5	90.6	92.5	91.8	90.4	89.2	85.9	81.6	76.9	70.4	65.1	61.6	61.5	61.4	60.7	54.8	97.0	99.4	
Bare Tapper	70.1	70.8	75.7	81.9	84.6	89.1	90.5	96.0	96.0	94.4	95.4	93.9	90.5	87.9	84.3	81.0	77.0	73.4	70.1	67.5	64.1	102.2	103.3	

(10) Oak Flooring	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
	Men's Sneaker	69.6	70.8	73.0	73.3	67.8	70.5	68.6	68.1	64.6	63.7	61.7	58.6	54.9	51.9	49.7	49.5	50.6	49.4	45.5	42.6	40.3	72.8	80.1
Men's Rubber	67.5	71.1	75.0	80.2	74.2	77.0	76.1	72.2	68.0	65.8	65.1	59.4	55.1	51.1	47.9	45.3	44.0	42.3	41.7	41.6	38.0	77.7	84.8	
Men's Leather	68.8	71.4	75.8	79.0	78.5	81.7	84.5	84.9	83.0	80.6	76.9	73.1	68.1	64.8	61.4	58.7	56.9	55.9	55.9	57.3	53.3	87.8	91.3	
Women's Sneaker	66.3	68.1	71.3	70.2	66.6	66.4	67.0	66.6	64.0	62.8	60.0	55.4	51.1	50.1	48.8	48.9	46.8	47.5	47.3	47.1	40.0	71.0	77.7	
Women's Rubber	67.3	70.1	72.8	73.5	68.5	68.8	65.0	65.7	63.3	61.5	60.6	55.5	51.4	48.2	45.9	43.3	42.8	41.5	39.1	39.5	34.7	71.1	79.2	
Women's Leather	67.8	71.6	76.3	82.4	79.7	83.6	85.7	86.7	87.6	86.3	85.4	83.4	79.7	75.7	70.1	66.3	62.5	58.5	57.5	58.7	54.4	92.9	94.9	
Bare Tapper	66.6	70.2	75.7	82.1	79.9	83.5	86.8	88.8	90.4	91.8	92.8	92.2	90.4	88.8	86.0	84.3	82.6	81.9	77.9	75.1	71.1	100.1	100.4	

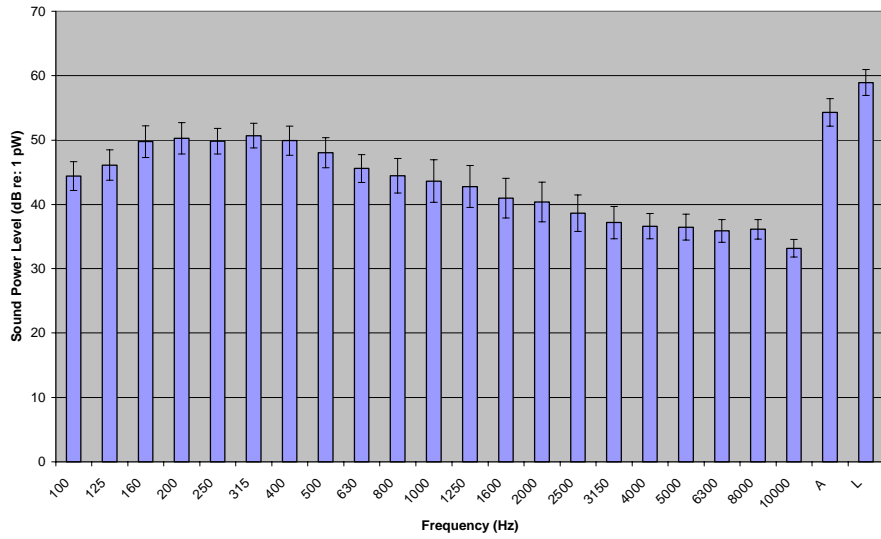
(11) Ceramic Tile	Center Freq. (Hz):	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	A	L
	Men's Sneaker	67.1	68.6	73.9	73.5	68.3	66.0	67.8	67.6	67.0	64.1	62.0	56.2	52.8	49.8	48.5	48.4	48.6	48.2	44.3	43.8	39.4	72.6	79.7
Men's Rubber	70.0	72.2	76.7	77.8	77.6	77.5	74.8	73.4	70.2	67.7	65.5	59.3	54.5	49.9	47.2	44.8	44.0	41.9	40.7	39.5	33.1	78.1	85.0	
Men's Leather	70.8	72.5	77.3	80.5	82.7	85.3	87.3	90.0	88.9	87.9	84.6	79.0	72.5	65.7	59.1	58.9	58.6	55.7	52.9	51.8	47.7	93.4	96.1	
Women's Sneaker	64.5	66.8	70.9	69.1	65.6	65.4	64.8	64.9	63.9	63.7	61.7	55.5	51.2	48.4	49.2	52.8	52.1	55.1	56.4	55.2	46.0	71.0	77.0	
Women's Rubber	66.3	69.0	76.6	76.6	71.9	67.6	63.2	66.0	63.7	60.9	61.3	52.7	49.3	44.8	43.8	41.8	43.5	42.8	42.0	40.9	37.2	72.2	81.4	
Women's Leather	69.0	71.9	77.9	81.5	84.1	87.5	90.1	93.4	93.9	94.5	92.3	89.5	84.6	79.3	73.2	69.8	67.2	63.2	59.7	59.1	54.9	99.4	101.0	
Bare Tapper	68.7	69.3	77.1	80.1	83.4	87.1	91.0	95.0	97.2	99.4	101.0	100.7	97.7	95.1	91.7	89.4	87.5	85.5	82.4	80.4	75.4	107.4	107.5	

All Amplitudes are Sound Power Level (dB, re: 1 picoWatt)

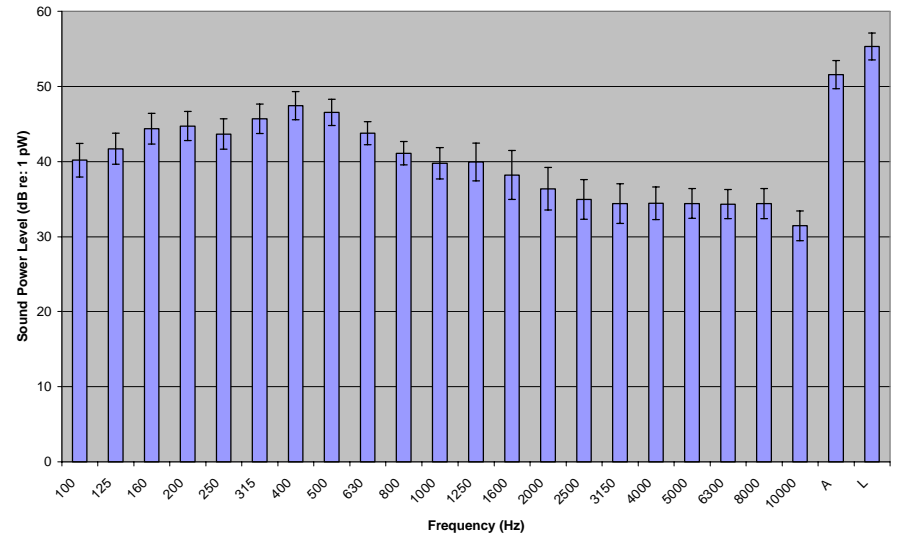
Red: band below background

Appendix A3: Human Subjects Power Spectra Graphs

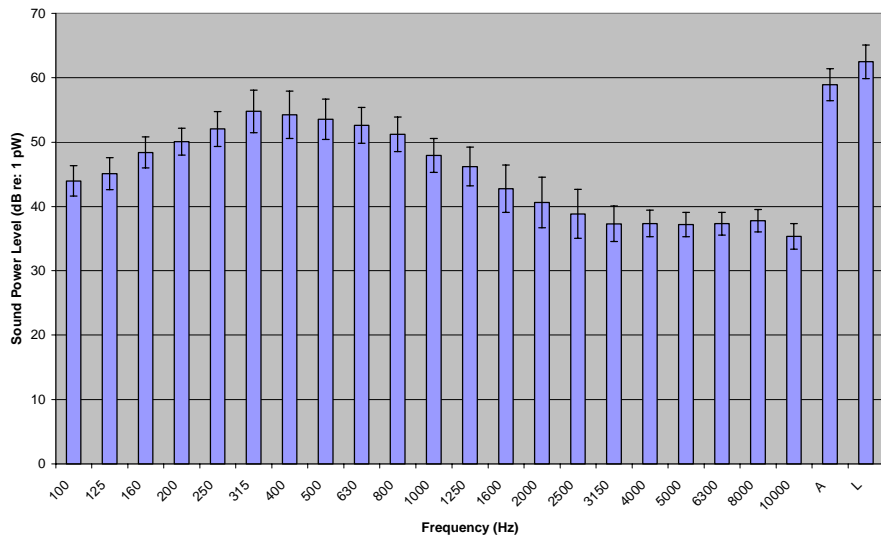
Men's Sneaker on Concrete



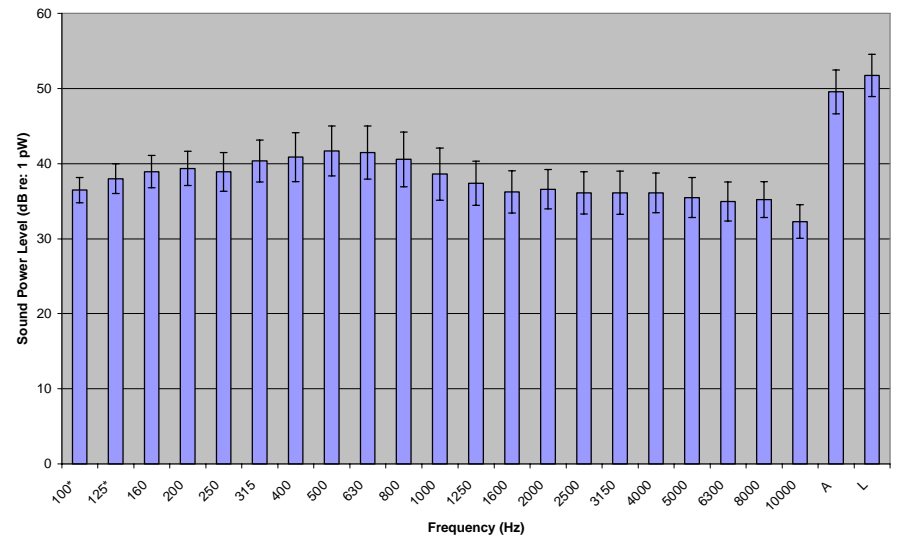
Men's Rubber Sole on Concrete



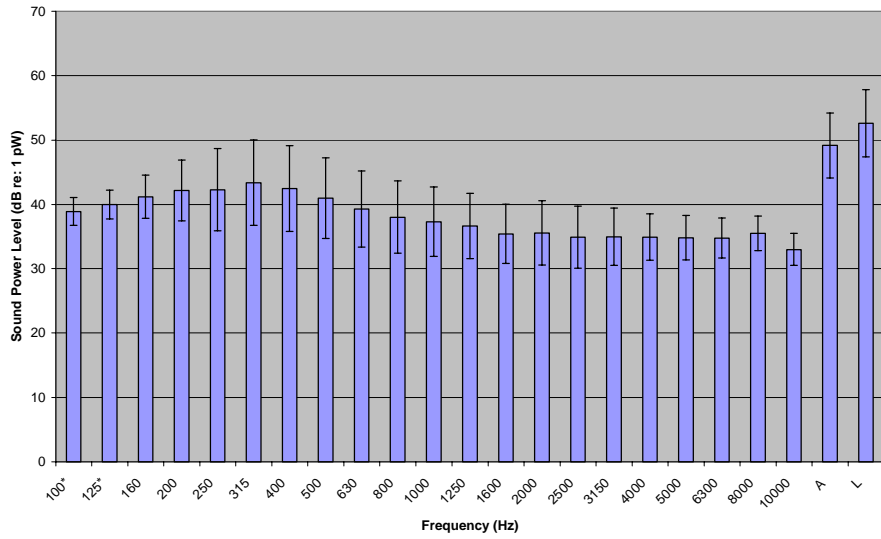
Men's Leather Sole on Concrete



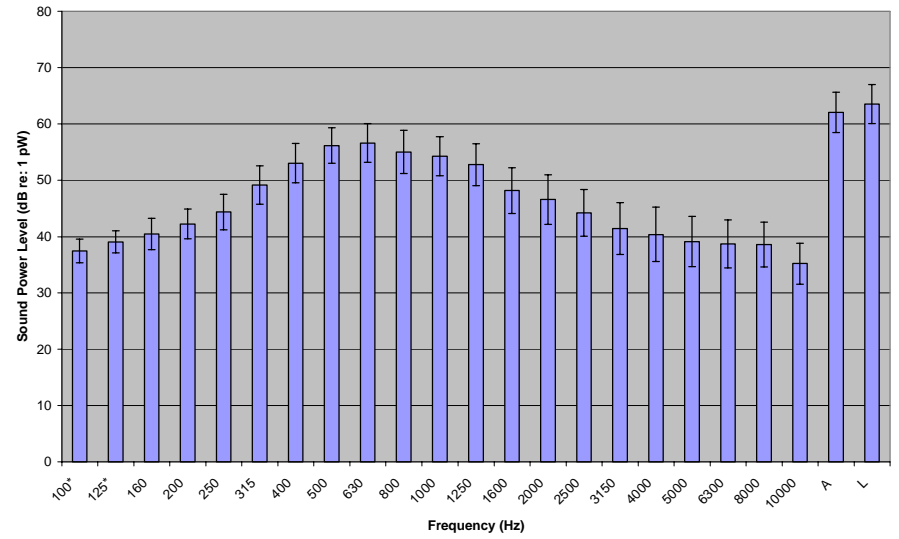
Women's Sneaker on Concrete



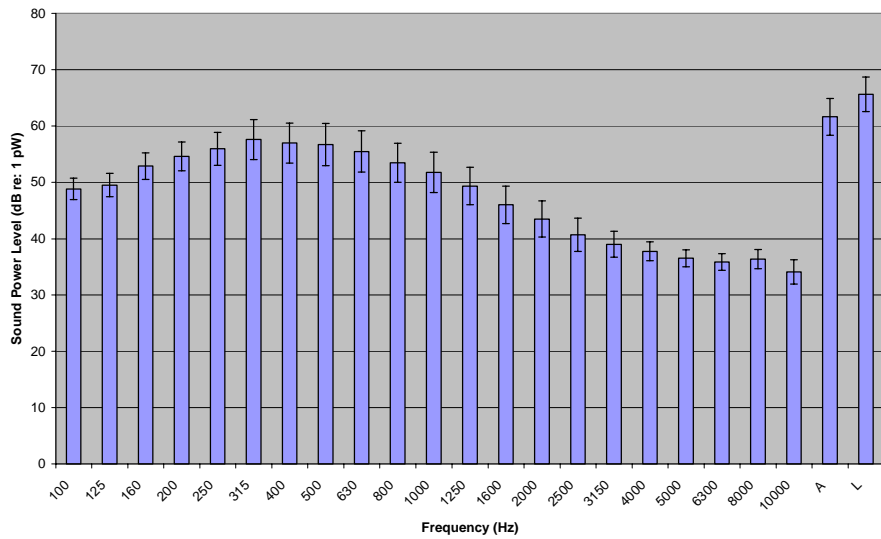
Women's Rubber Sole on Concrete



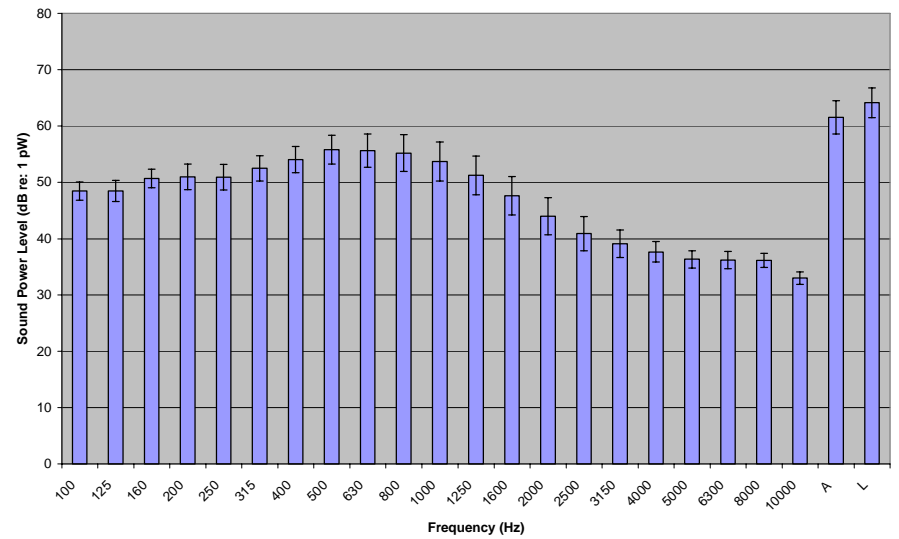
Women's Leather Sole on Concrete



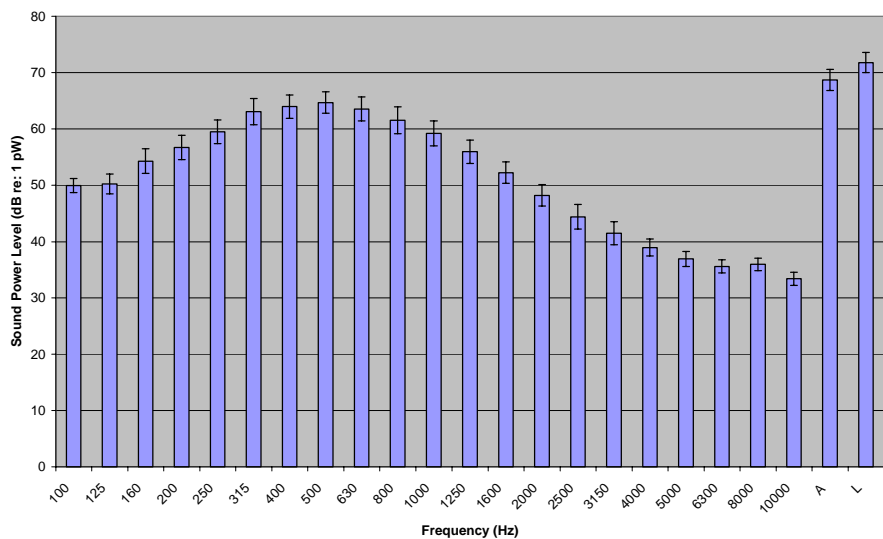
Men's Sneaker on Sub-floor



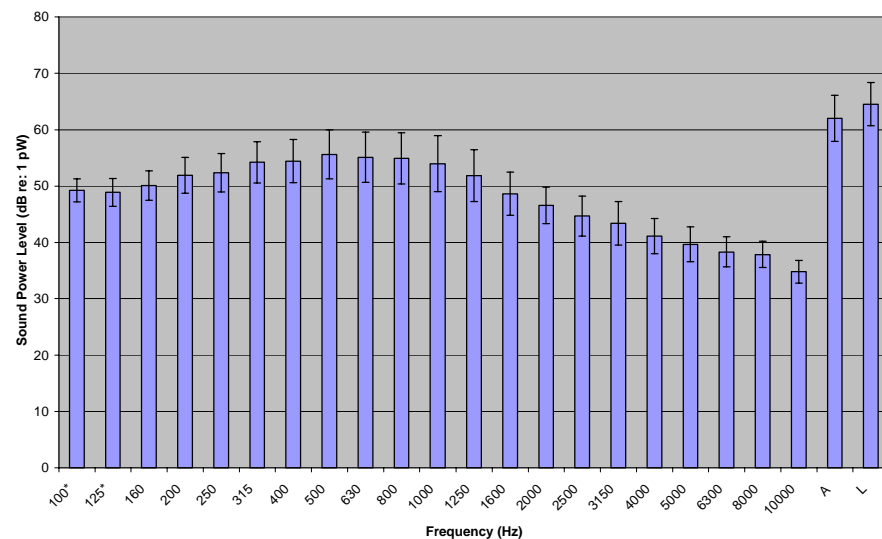
Men's Rubber Sole on Sub-floor



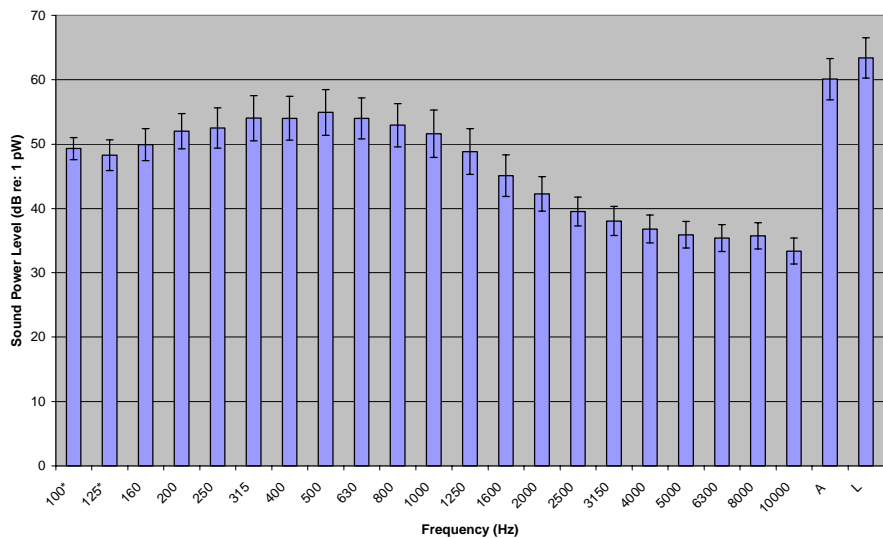
Men's Leather Sole on Sub-floor



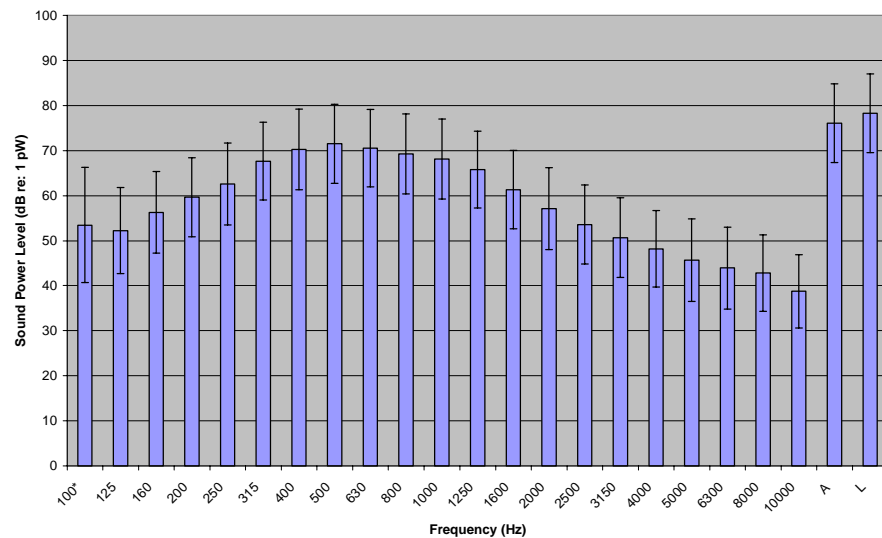
Women's Sneaker on Sub-floor



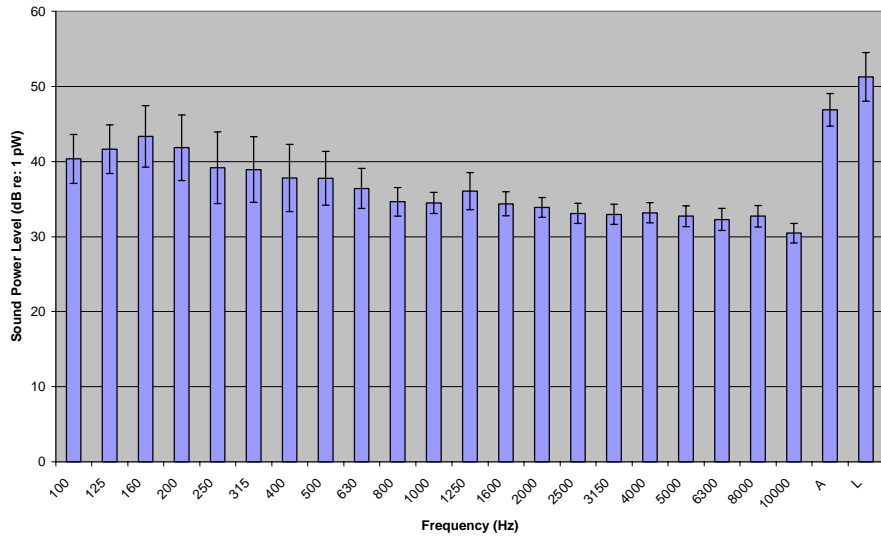
Women's Rubber Sole on Sub-floor



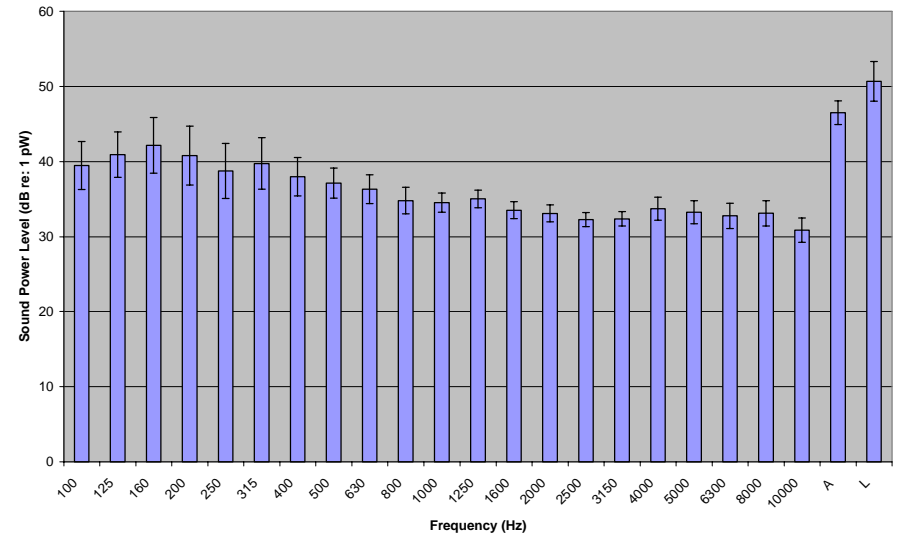
Women's Leather Sole on Sub-floor



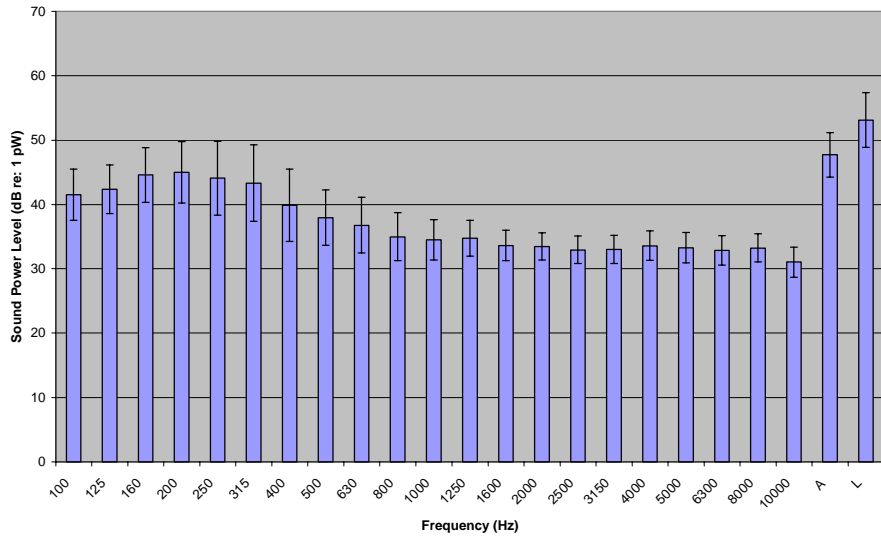
Men's Sneaker on Carpet on Concrete



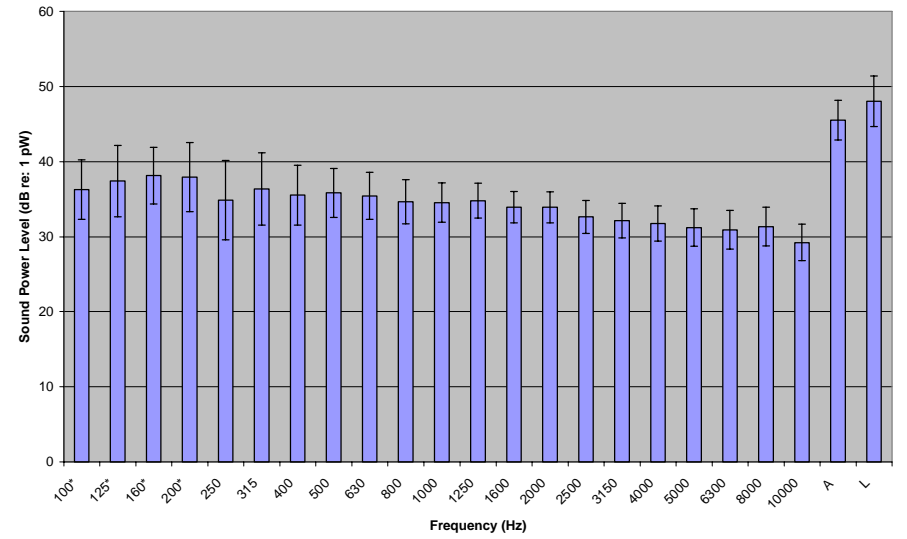
Men's Rubber Sole on Carpet on Concrete



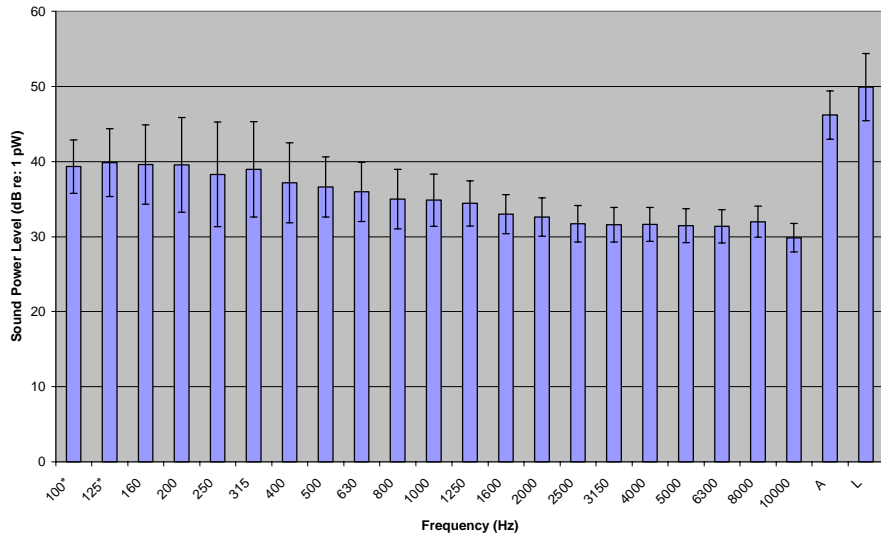
Men's Leather Sole on Carpet on Concrete



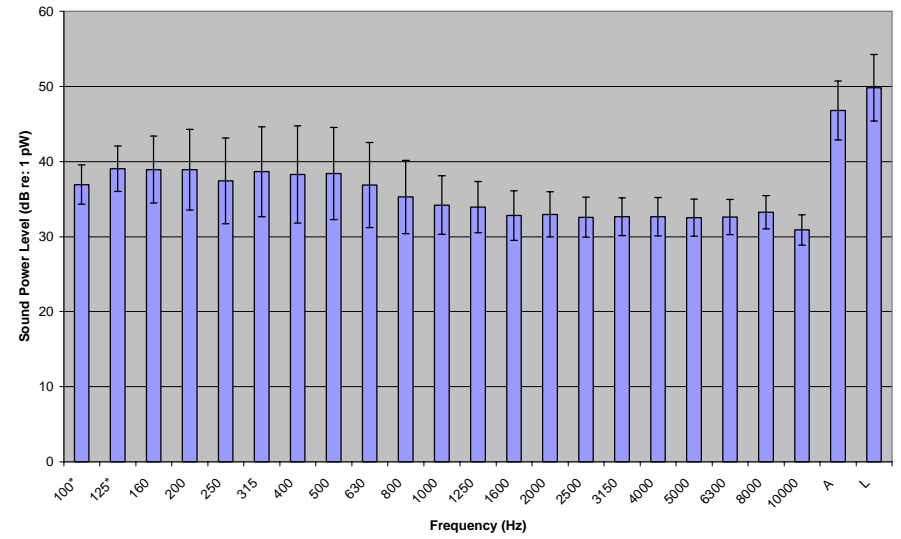
Women's Sneaker on Carpet on Concrete



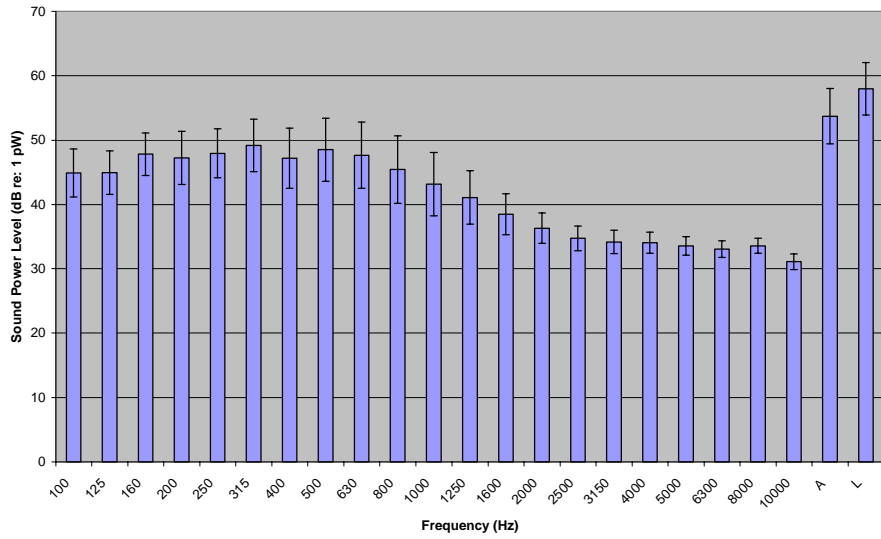
Women's Rubber Sole on Carpet on Concrete



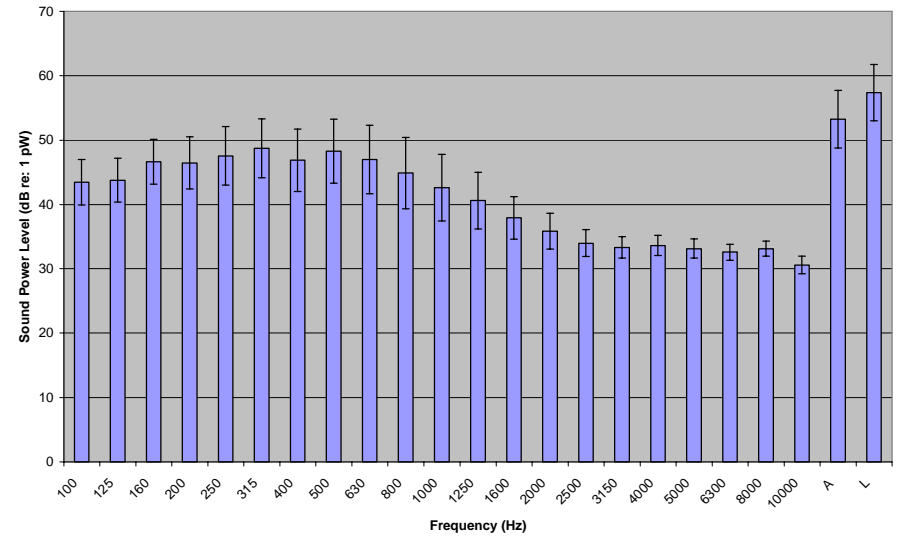
Women's Leather Sole on Carpet on Concrete



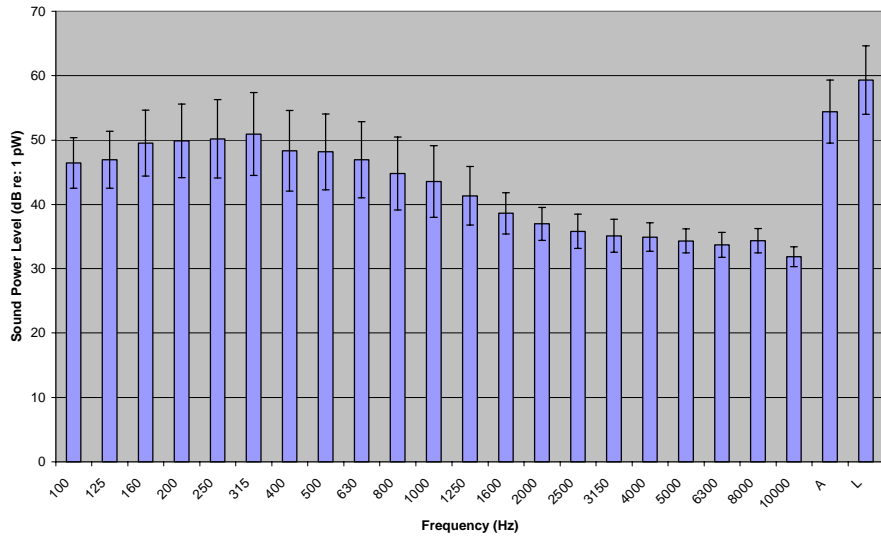
Men's Sneaker on Carpet on Sub-floor



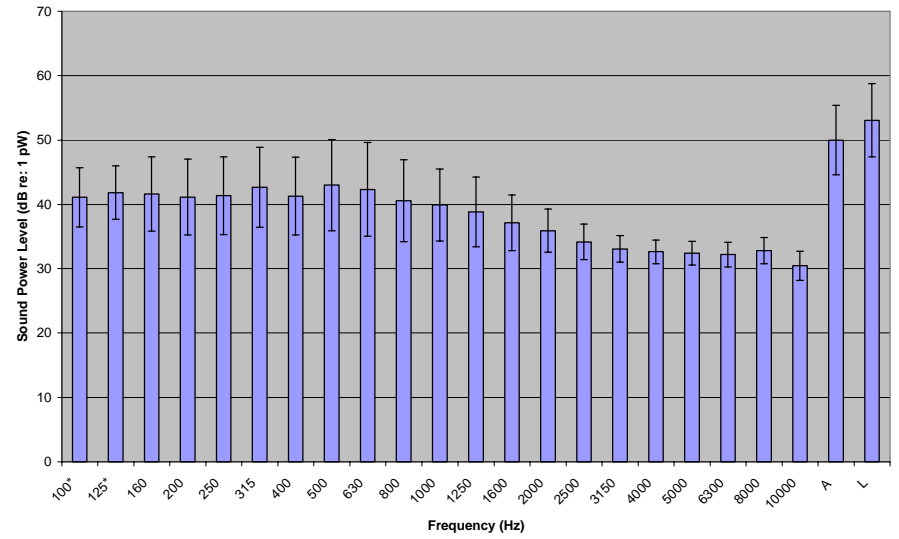
Men's Rubber Sole on Carpet on Sub-floor



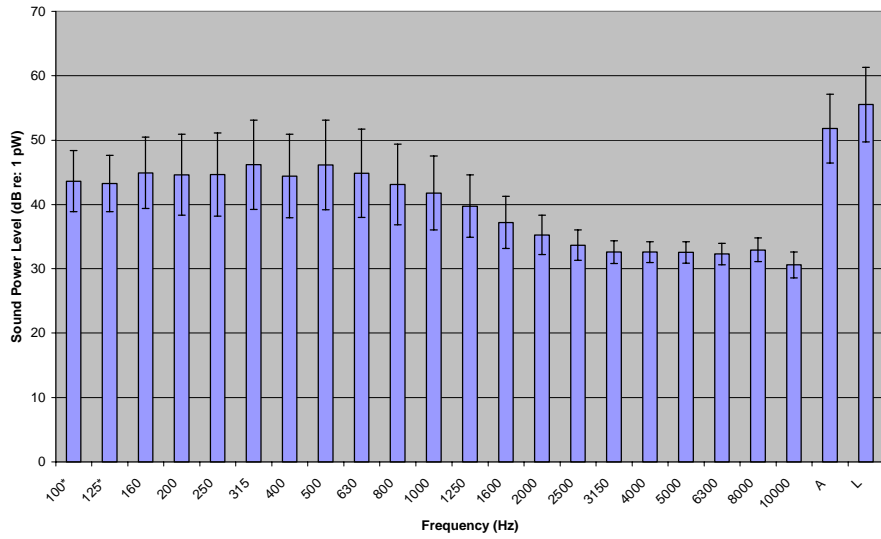
Men's Leather Sole on Carpet on Sub-floor



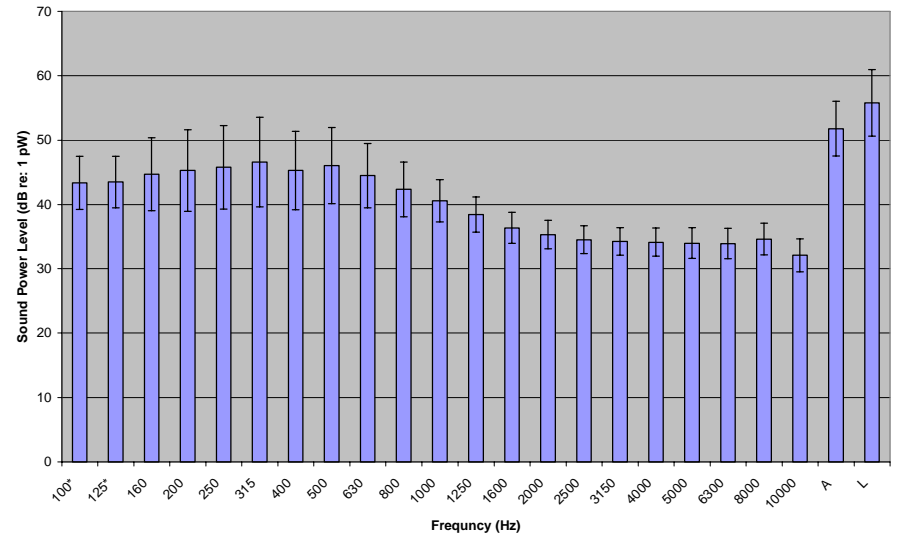
Women's Sneaker on Carpet on Sub-floor



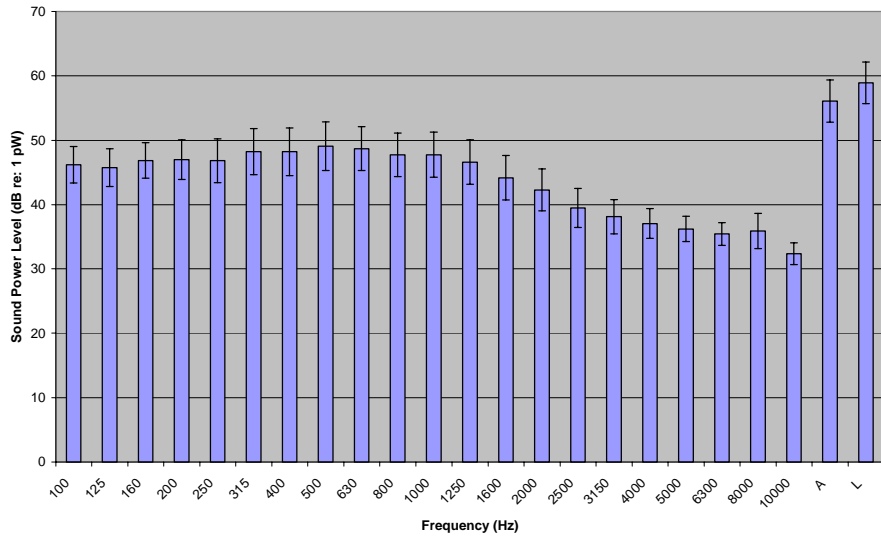
Women's Rubber Sole on Carpet on Sub-floor



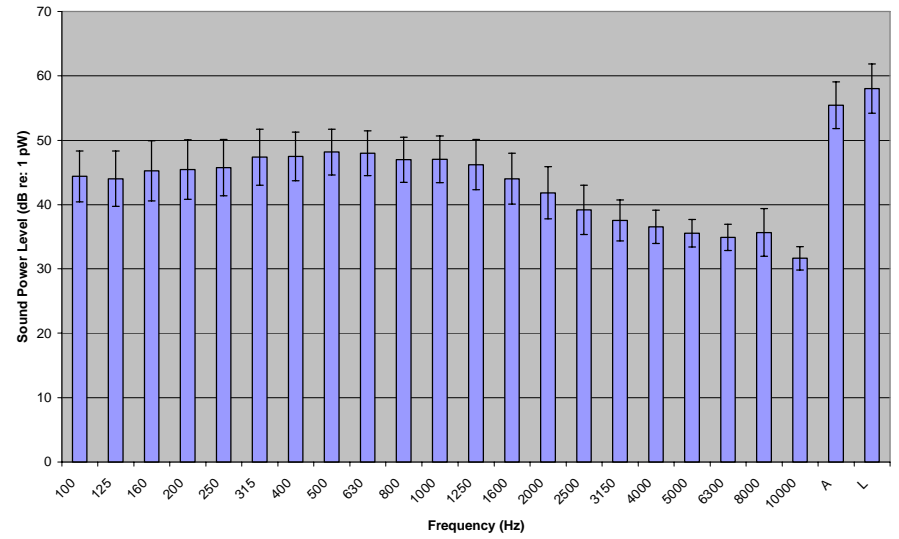
Women's Leather Sole on Carpet on Sub-floor



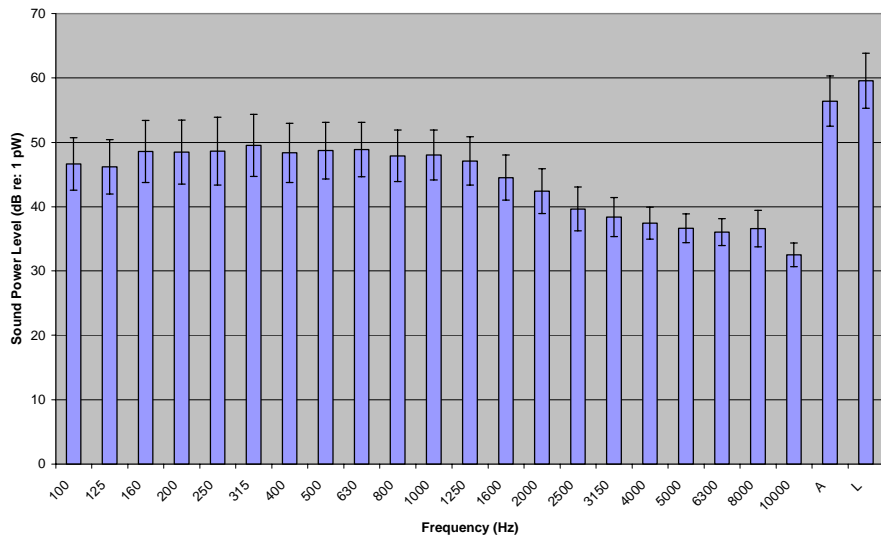
Men's Sneaker on Wool Carpet



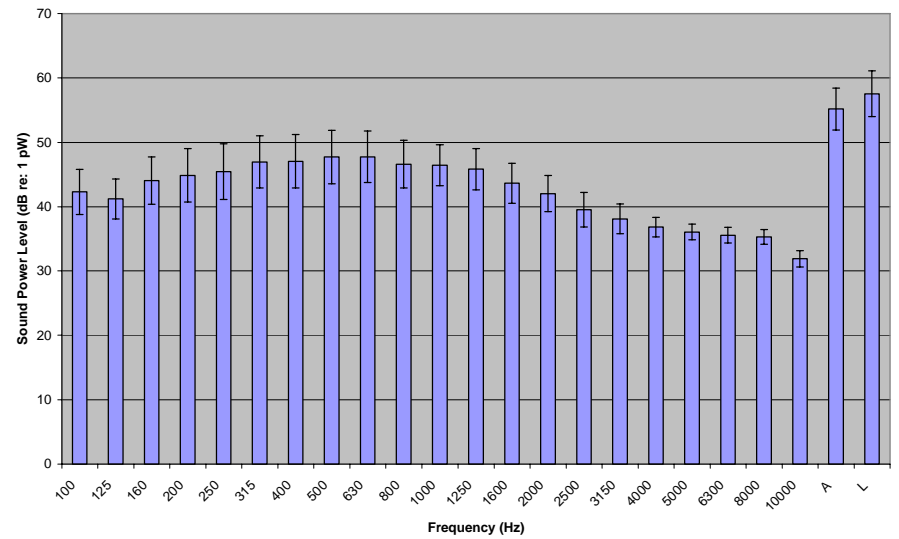
Men's Rubber Sole on Wool Carpet



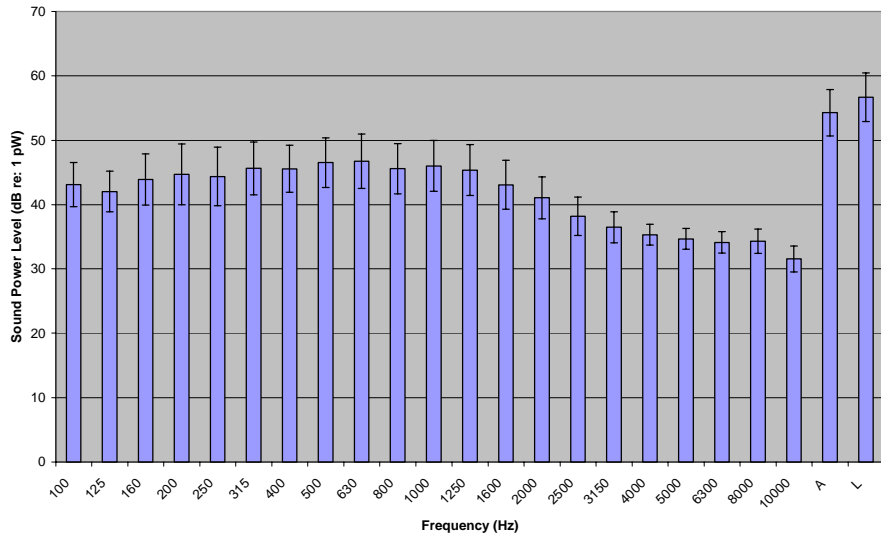
Men's Leather Sole on Wool Carpet



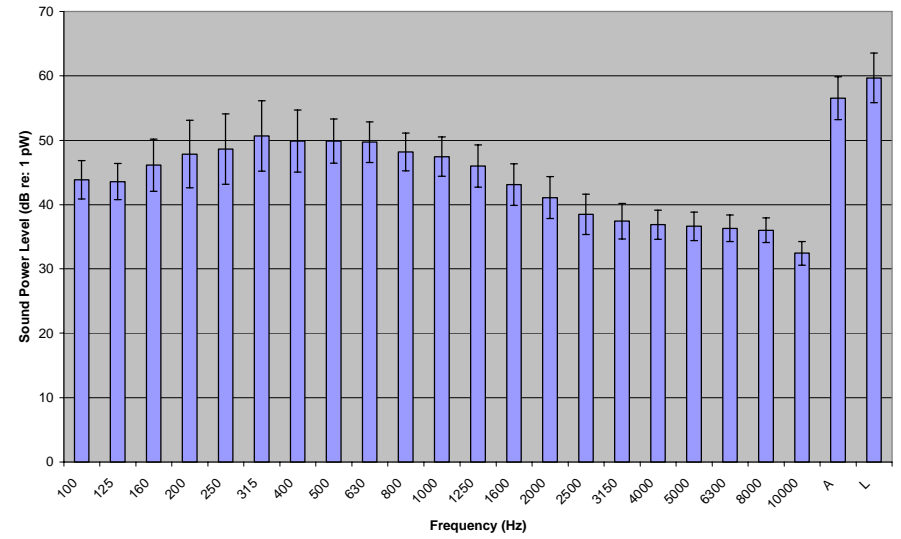
Women's Sneaker on Wool Carpet



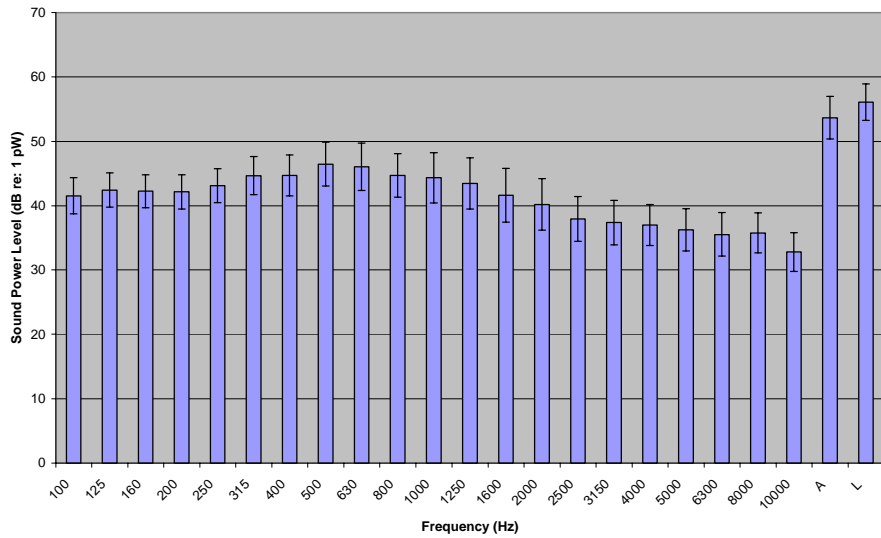
Women's Rubber Sole on Wool Carpet



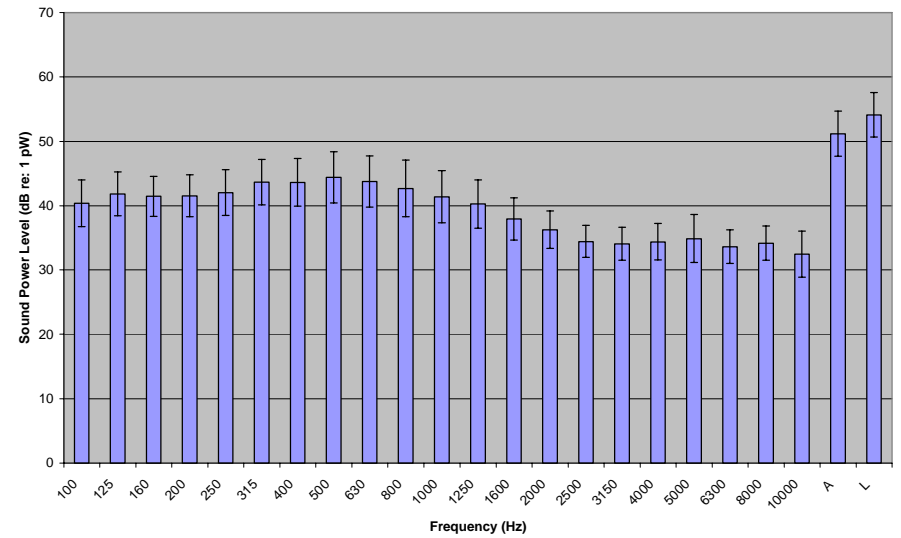
Women's Leather Sole on Wool Carpet



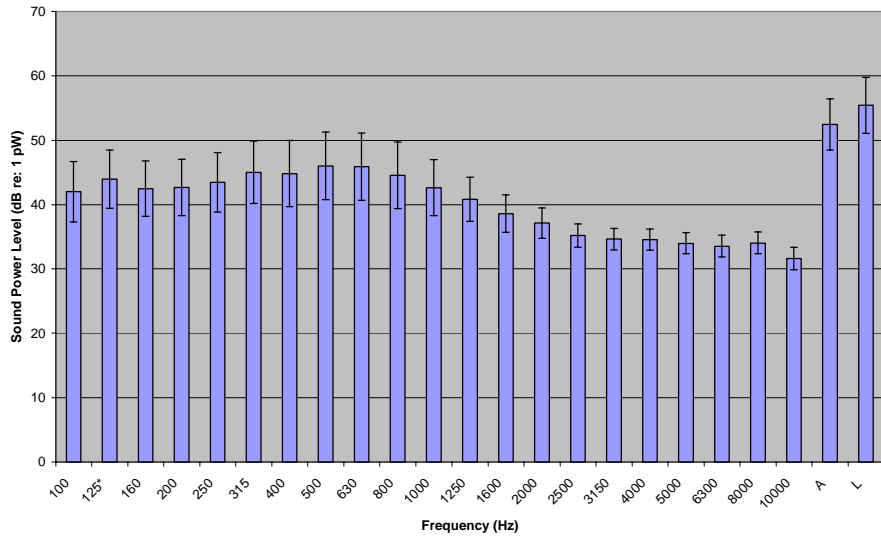
Men's Sneaker on Wool Carpet with Pad



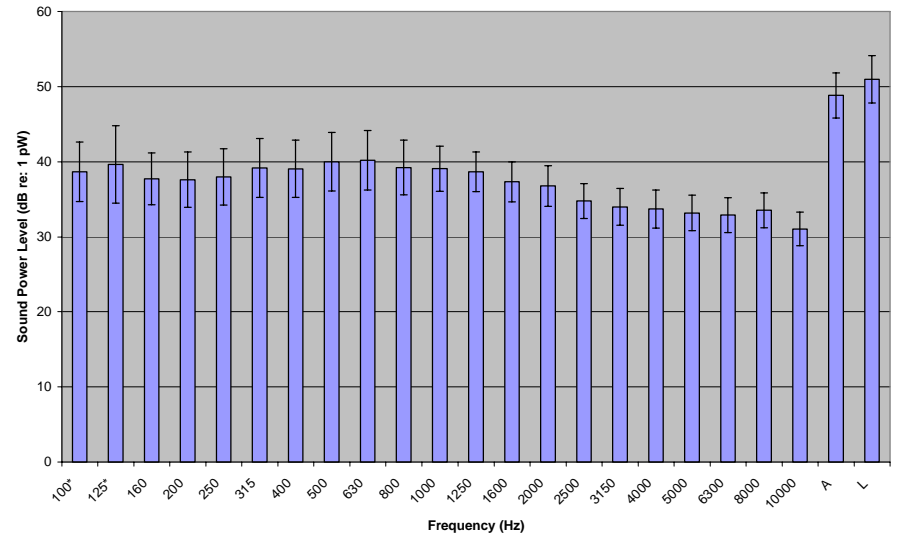
Men's Rubber Sole on Wool Carpet with Pad



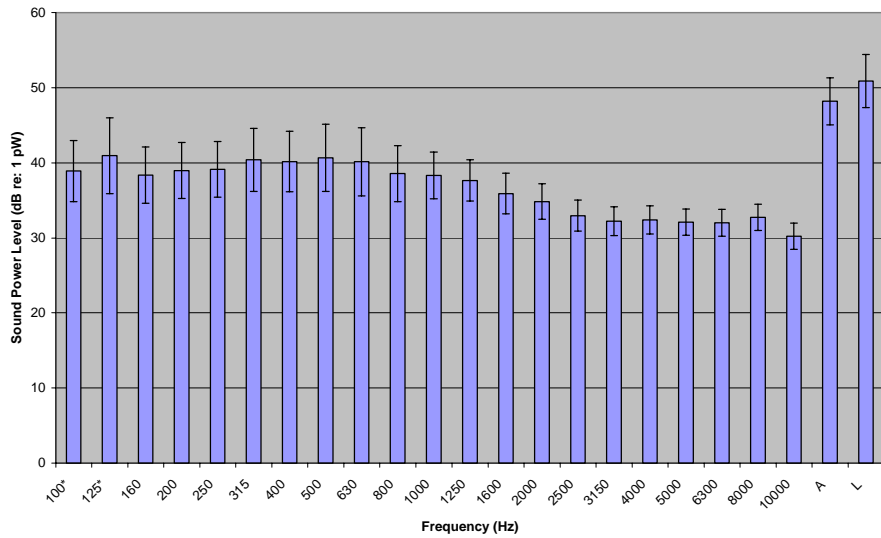
Men's Leather Sole on Wool Carpet with Pad



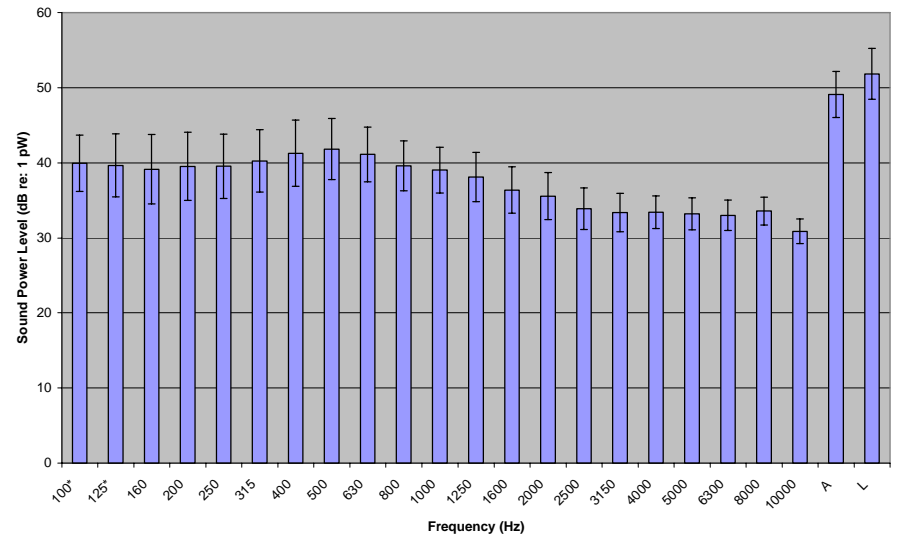
Women's Sneaker on Wool Carpet with Pad



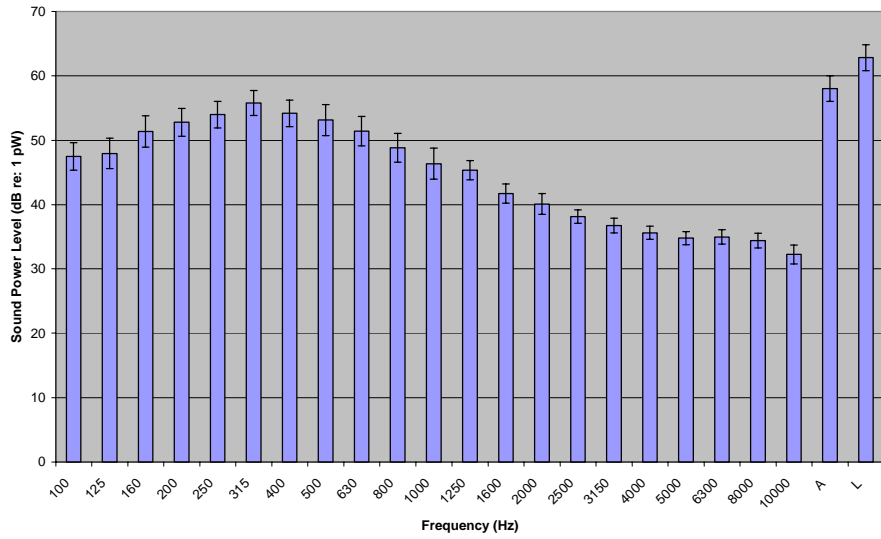
Women's Rubber Sole on Wool Carpet with Pad



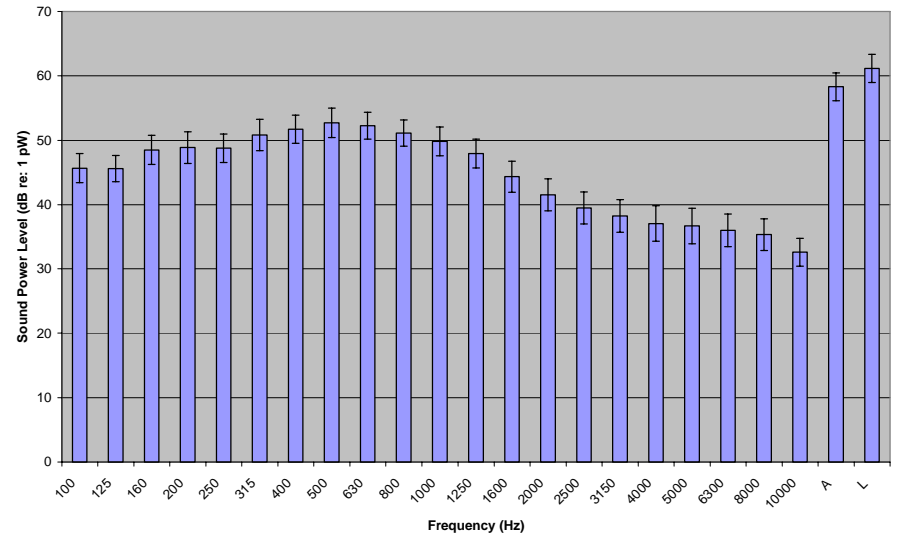
Women's Leather Sole on Wool Carpet with Pad



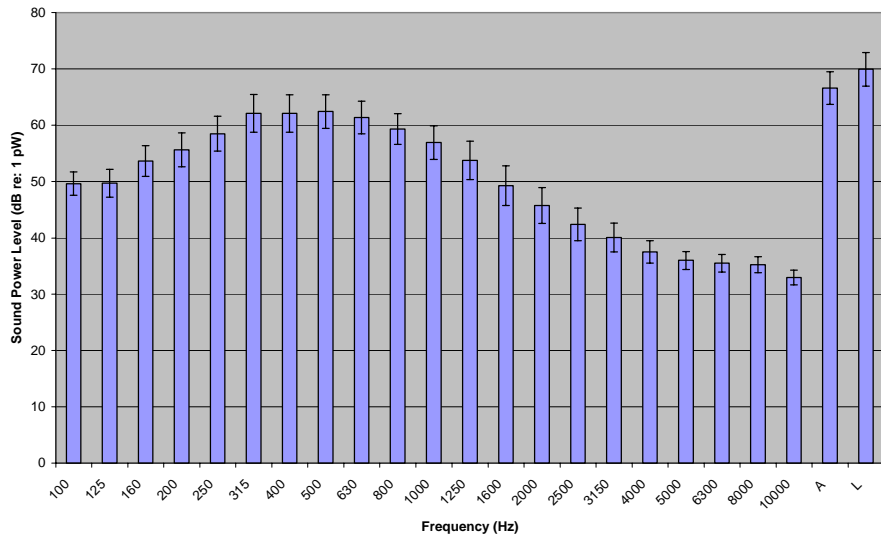
Men's Sneaker on Thin Vinyl



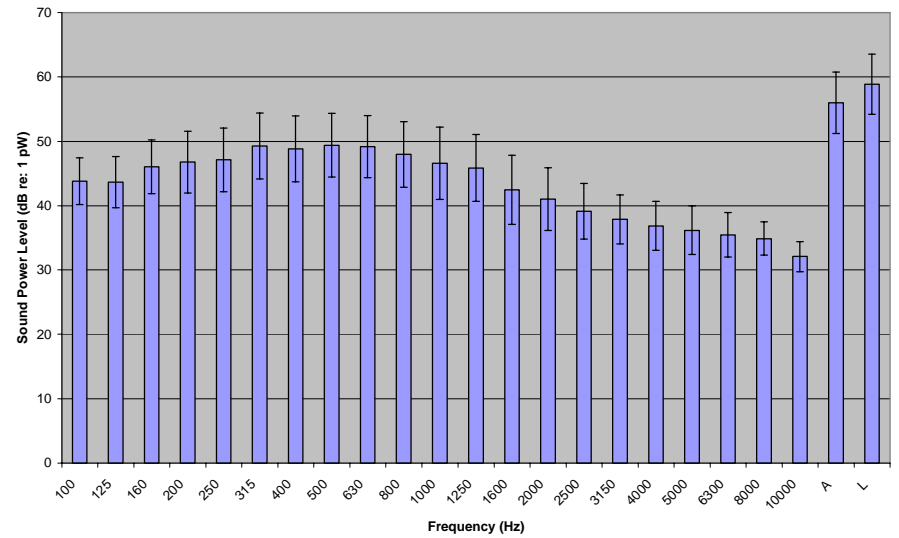
Men's Rubber Sole on Thin Vinyl



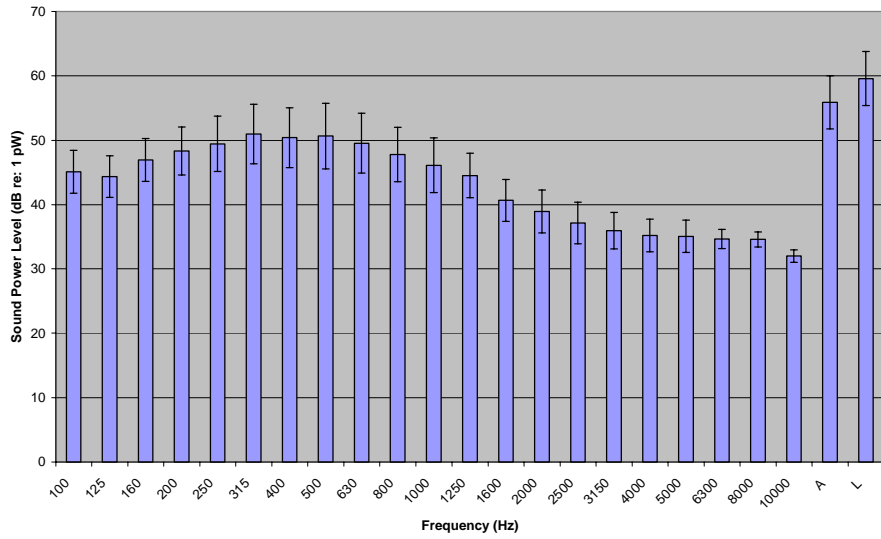
Men's Leather Sole on Thin Vinyl



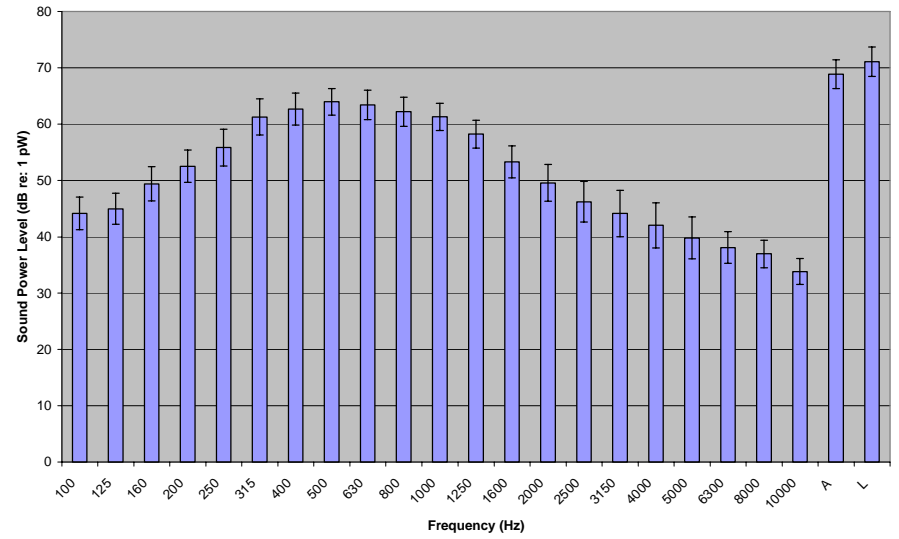
Women's Sneaker on Thin Vinyl



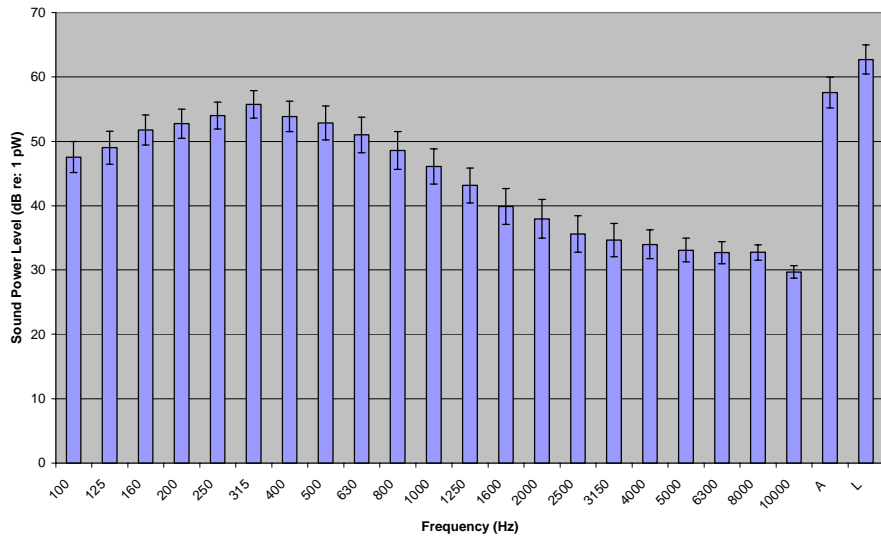
Women's Rubber Sole on Thin Vinyl



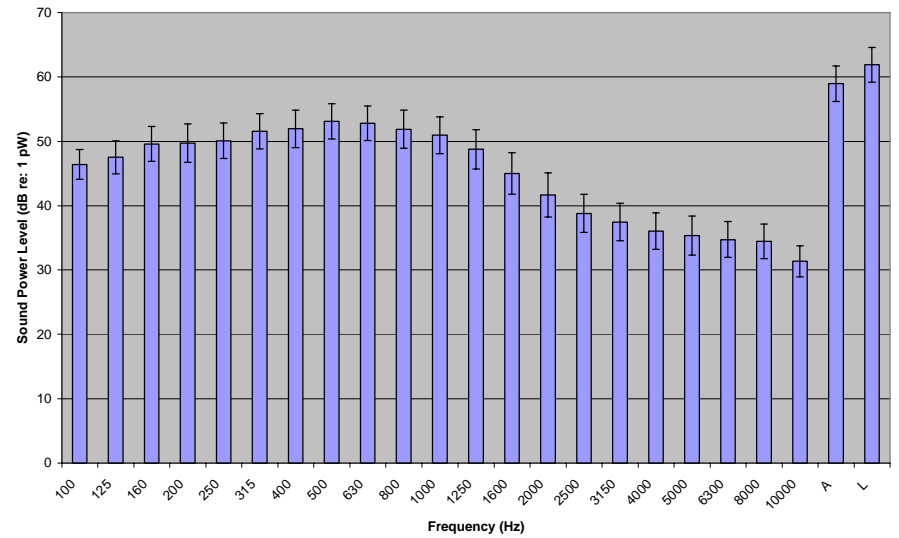
Women's Leather Sole on Thin Vinyl



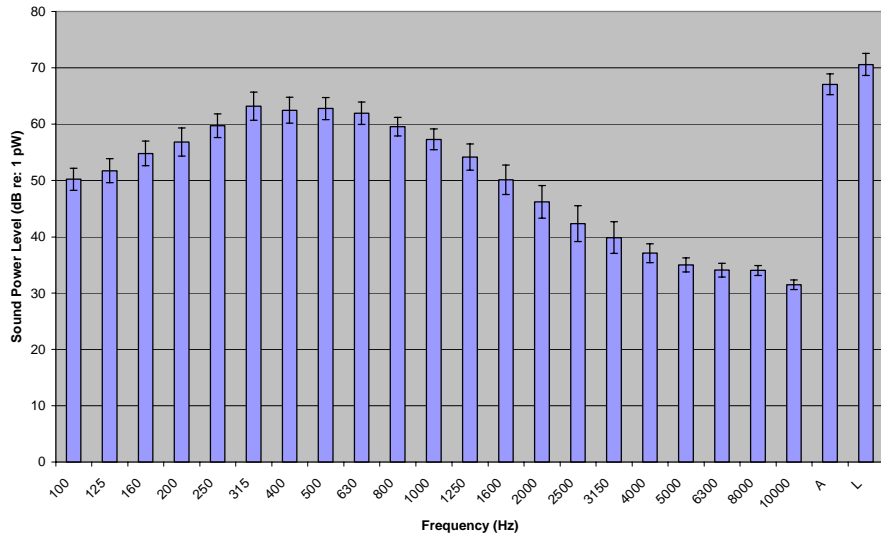
Men's Sneaker on Medium Vinyl



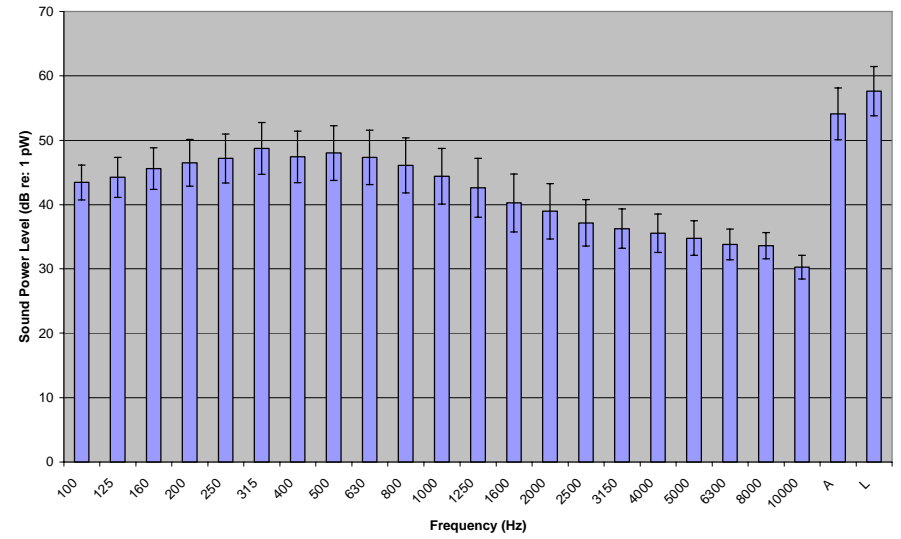
Men's Rubber Sole on Medium Vinyl



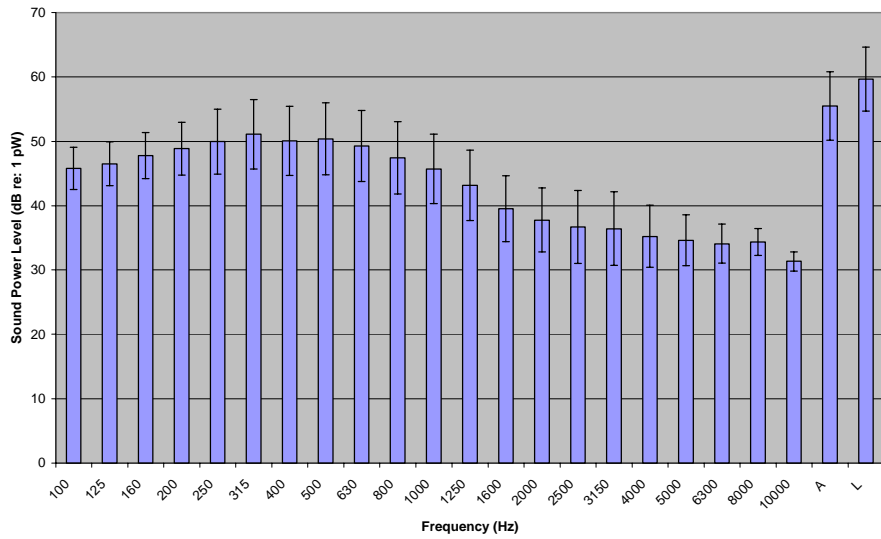
Men's Leather Sole on Medium Vinyl



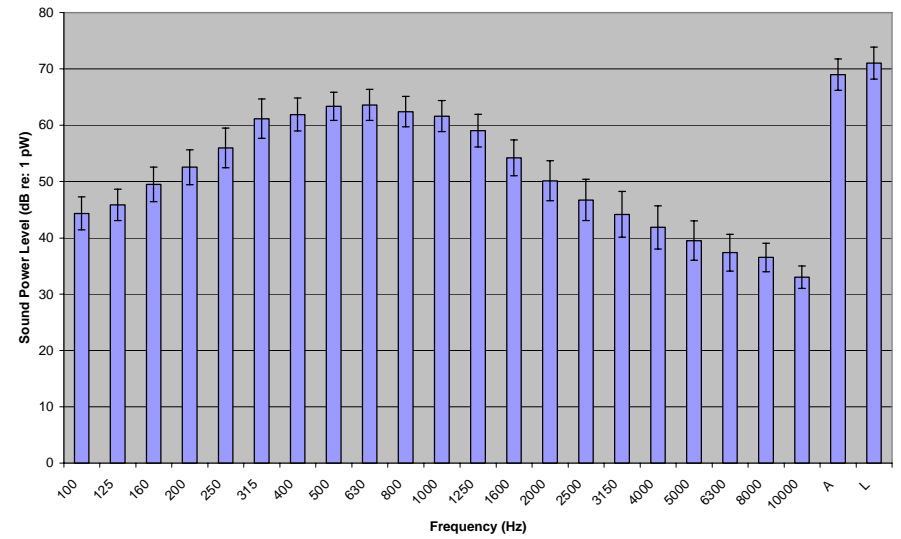
Women's Sneaker on Medium Vinyl



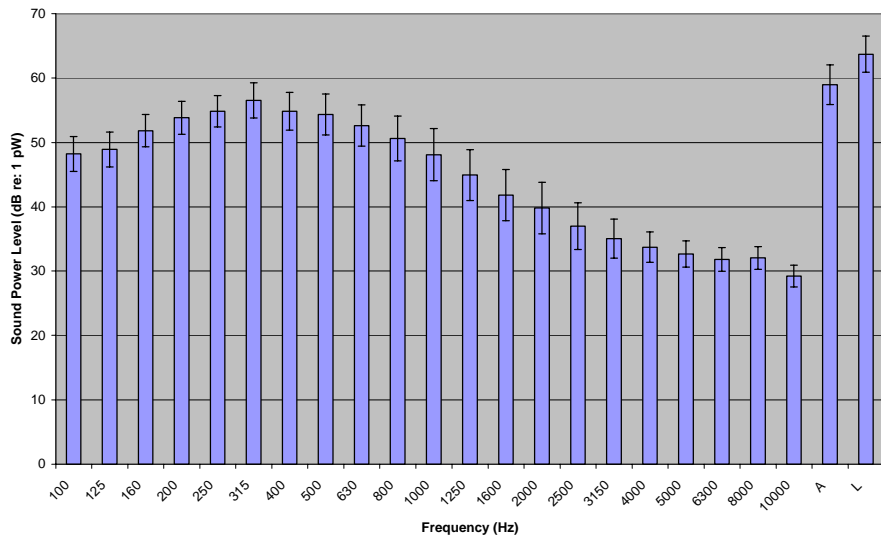
Women's Rubber Sole on Medium Vinyl



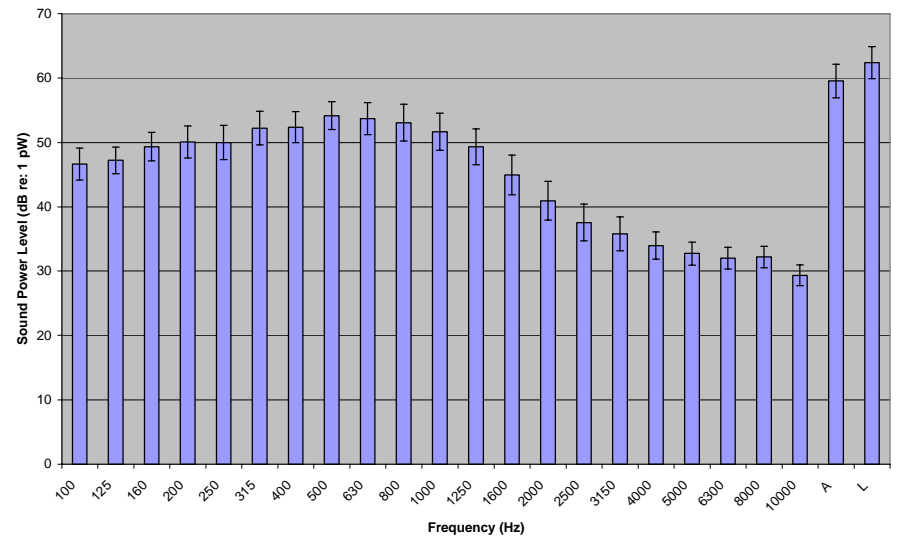
Women's Leather Sole on Medium Vinyl



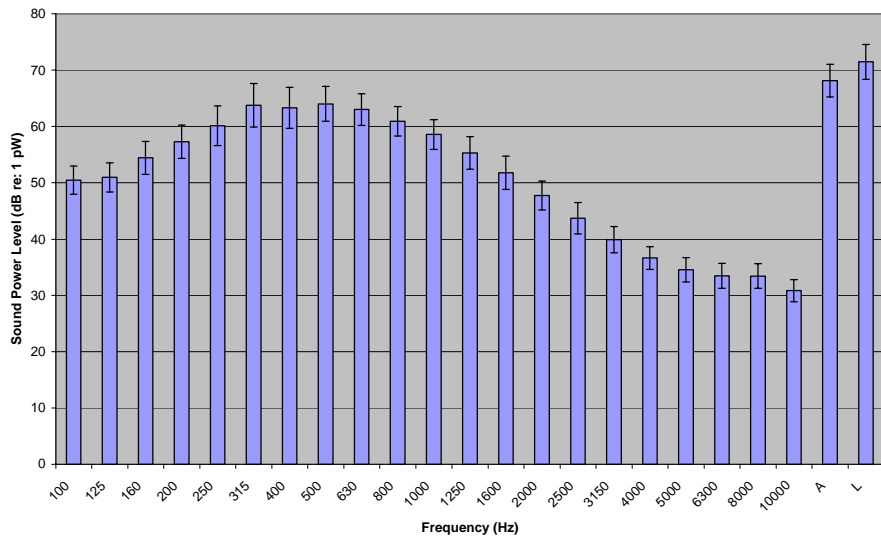
Men's Sneaker on Thick Vinyl



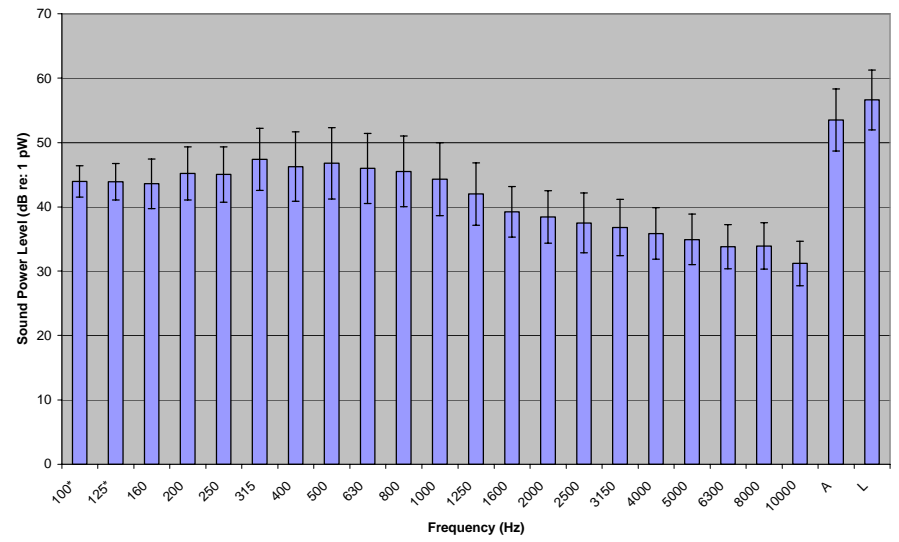
Men's Rubber Sole on Thick Vinyl



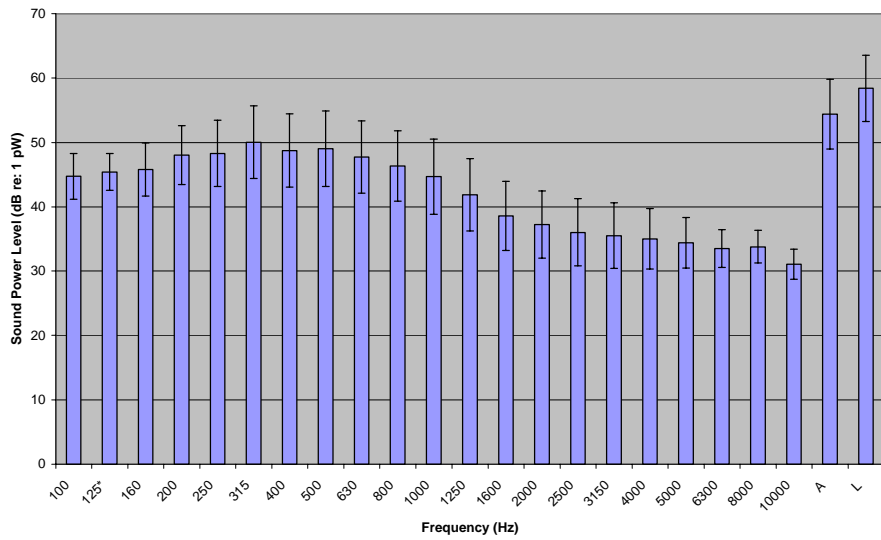
Men's Leather Sole on Thick Vinyl



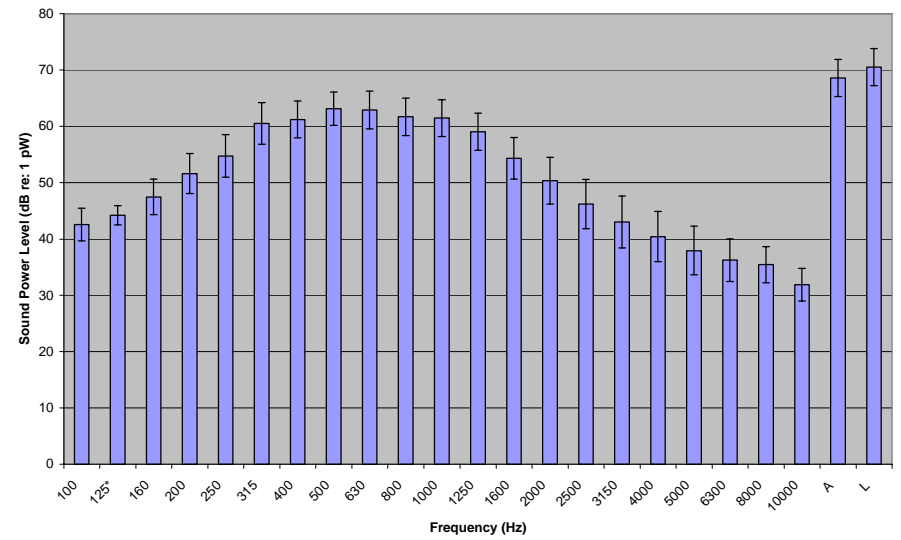
Women's Sneaker on Thick Vinyl



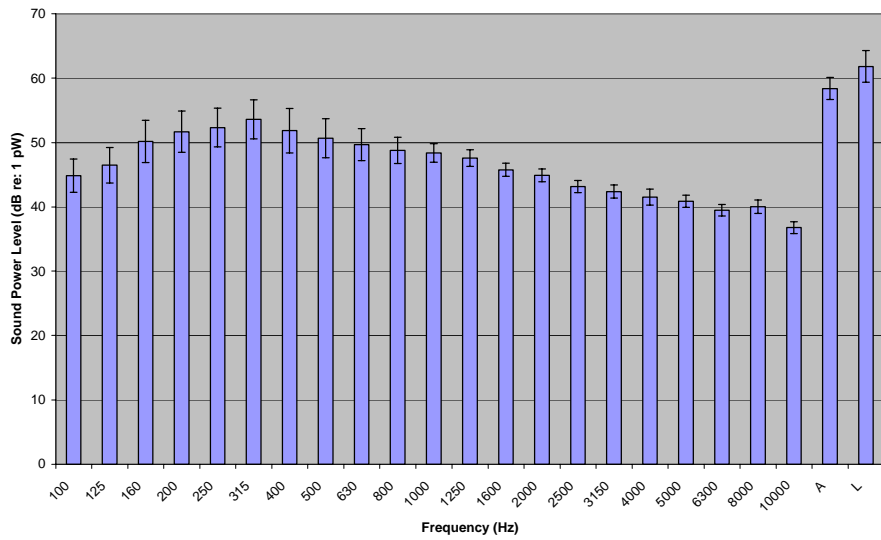
Women's Rubber Sole on Thick Vinyl



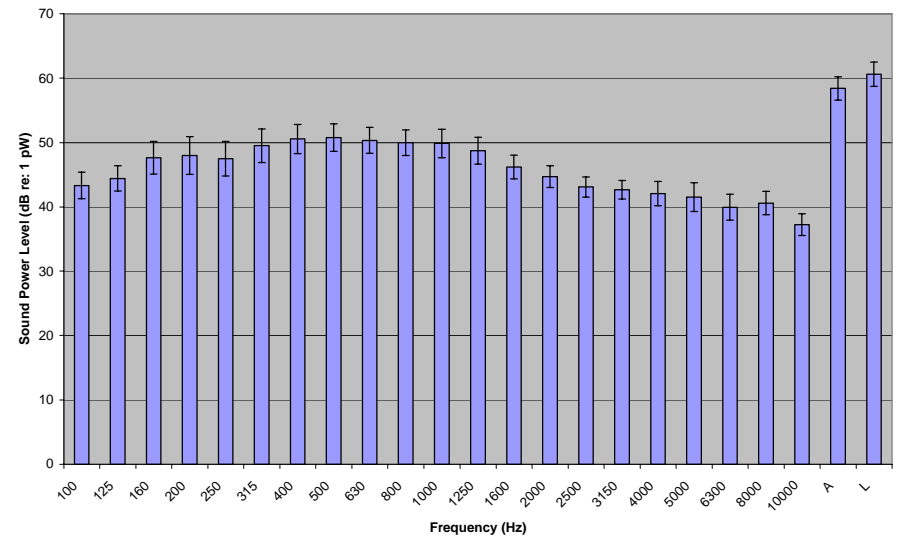
Women's Leather Sole on Thick Vinyl



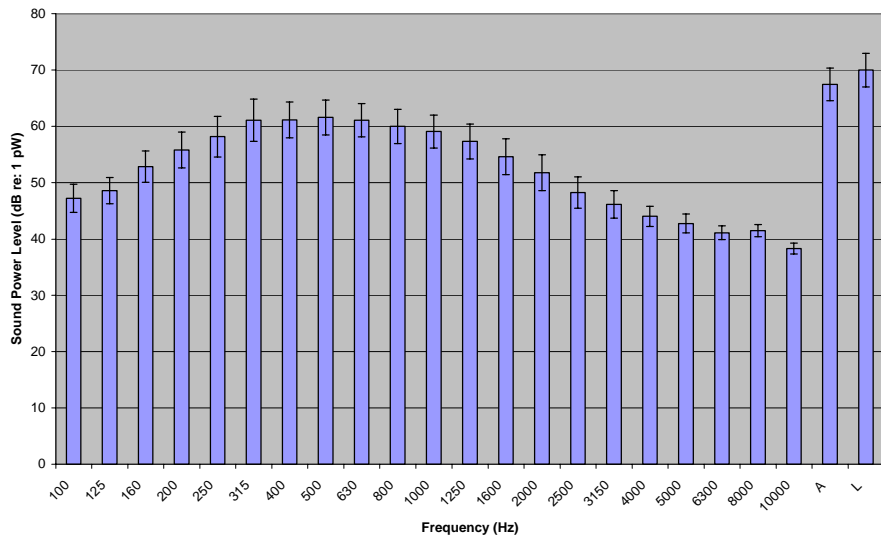
Men's Sneaker on Oak Floor



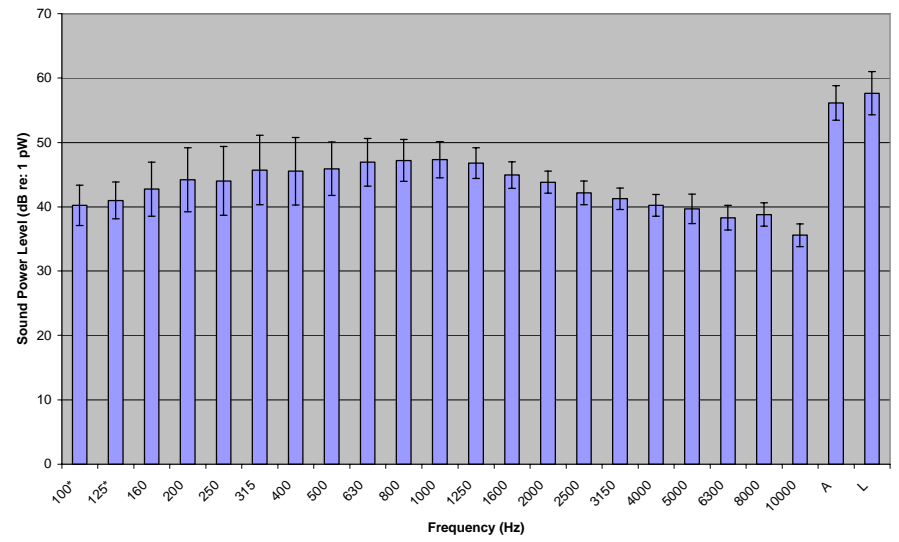
Men's Rubber Sole on Oak Floor



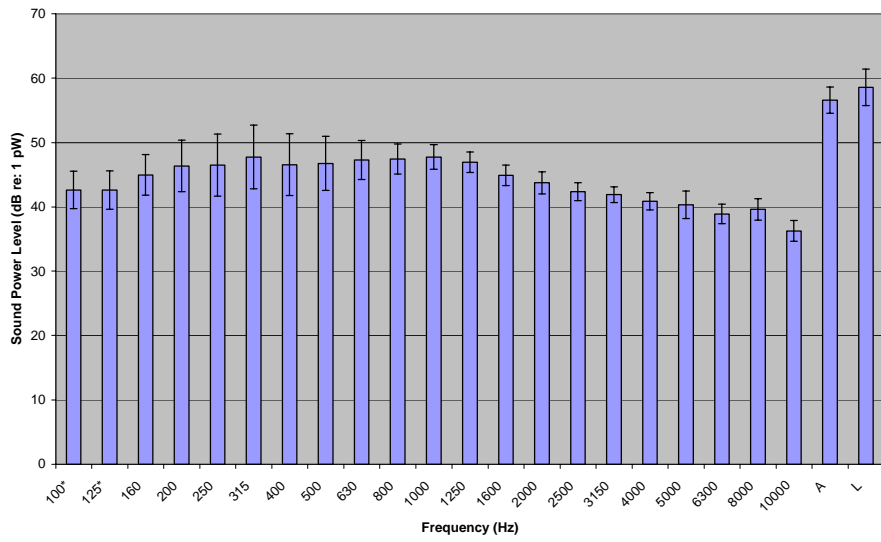
Men's Leather Sole on Oak Floor



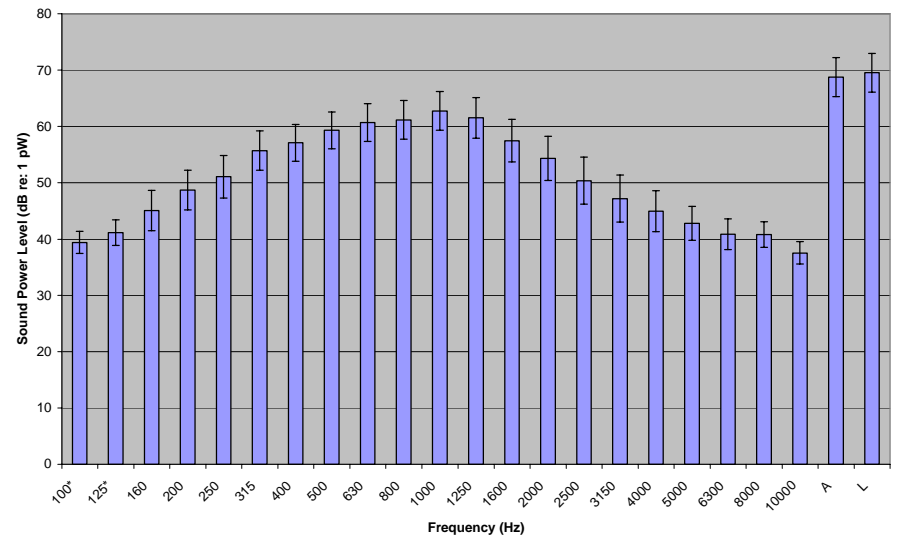
Women's Sneaker on Oak Floor



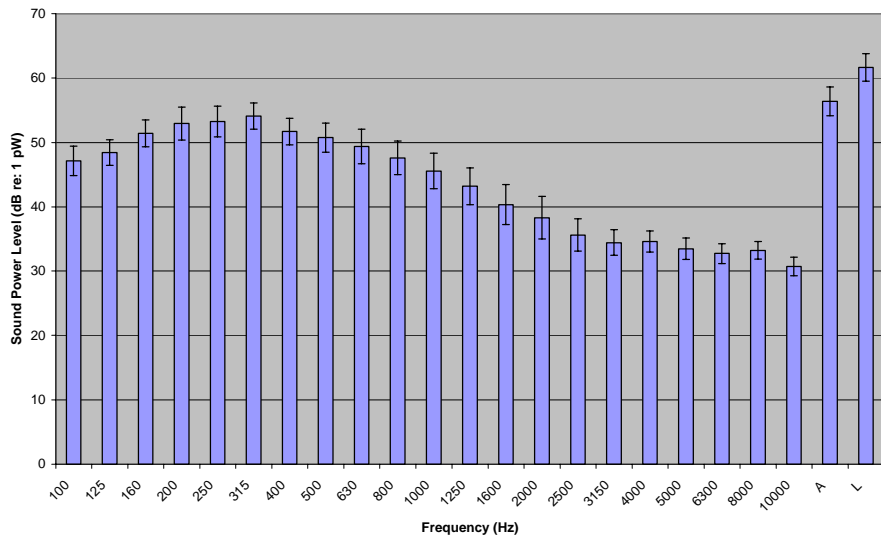
Women's Rubber Sole on Oak Floor



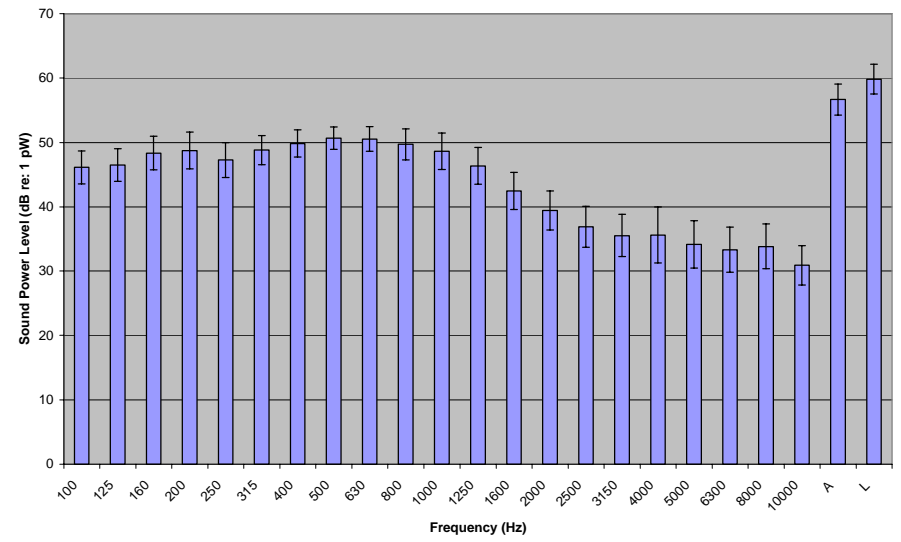
Women's Leather Sole on Oak Floor



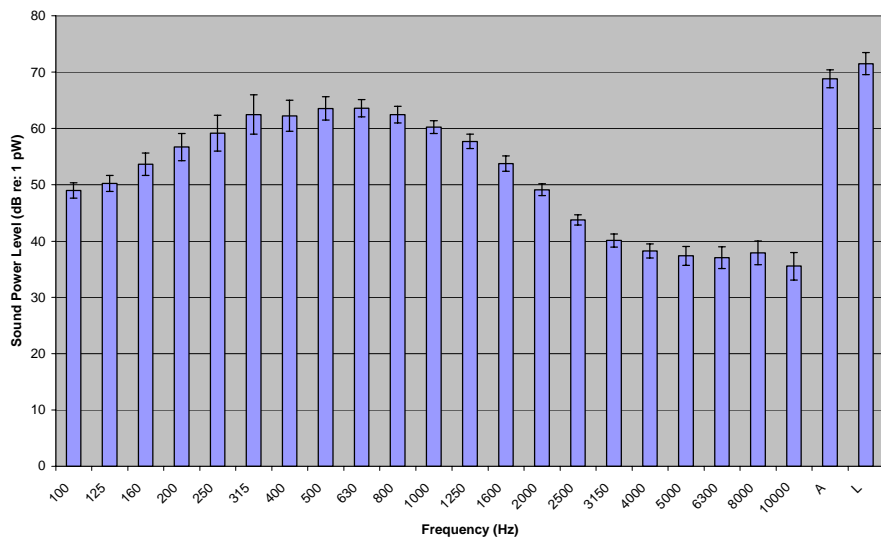
Men's Sneaker on Ceramic Tile



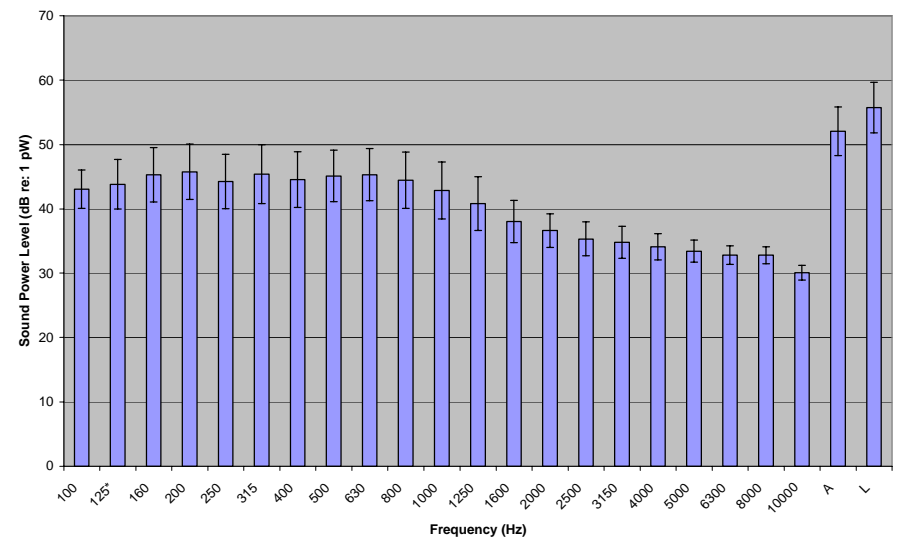
Men's Rubber Sole on Ceramic Tile



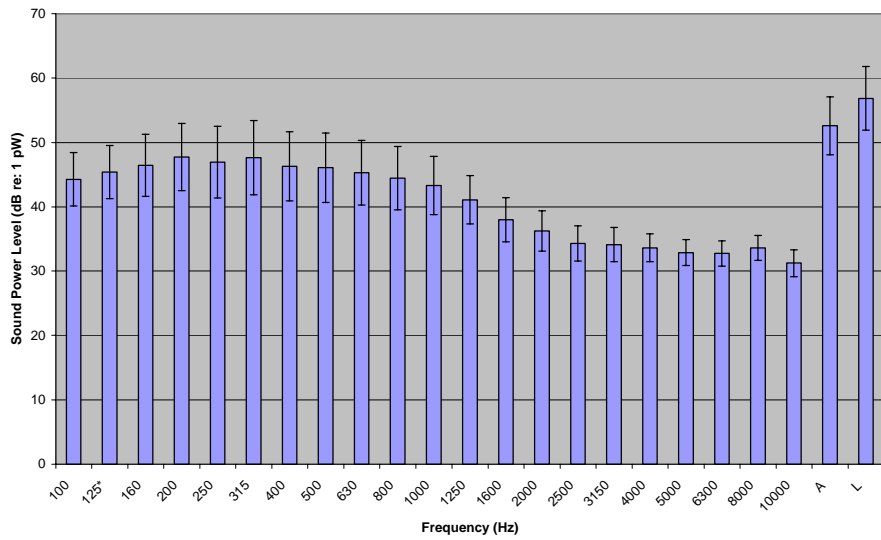
Men's Leather Sole on Ceramic Tile



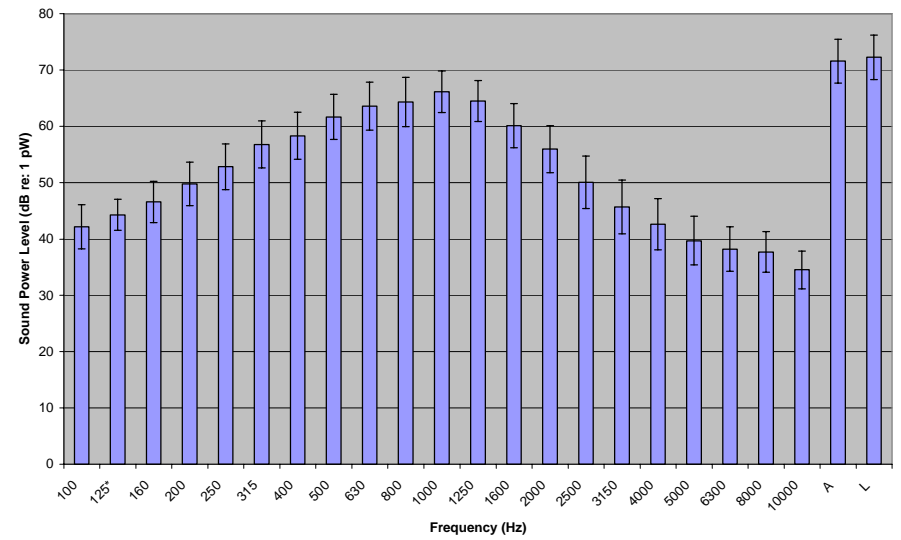
Women's Sneaker on Ceramic Tile



Women's Rubber Sole on Ceramic Tile

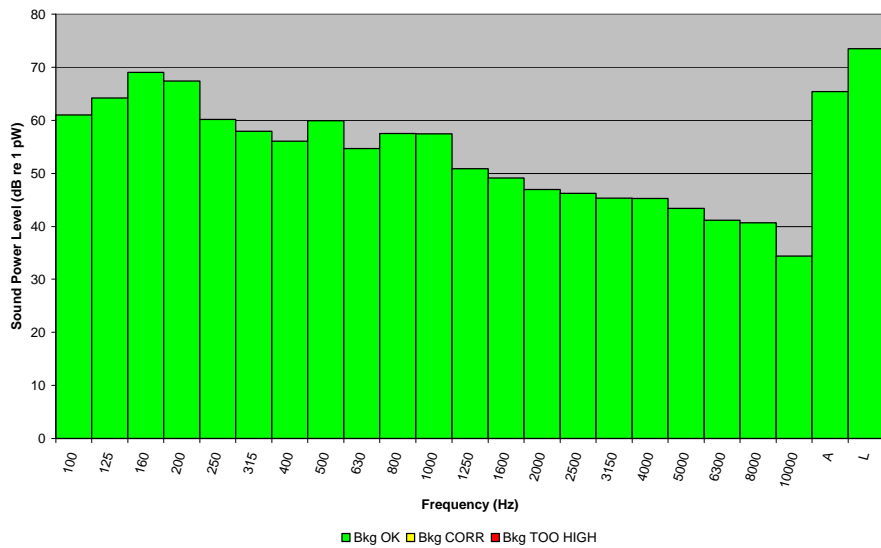


Women's Leather Sole on Ceramic Tile

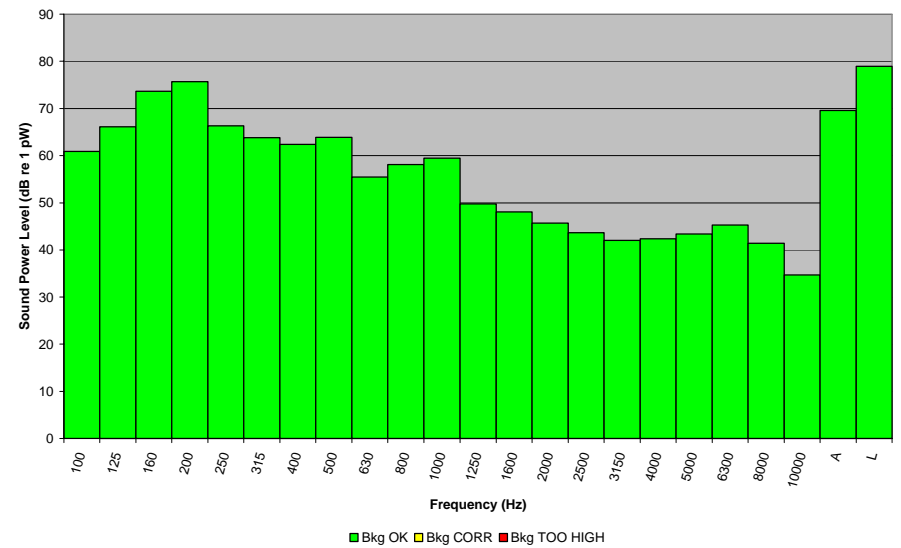


Appendix A4: Tapper Power Spectra Graphs

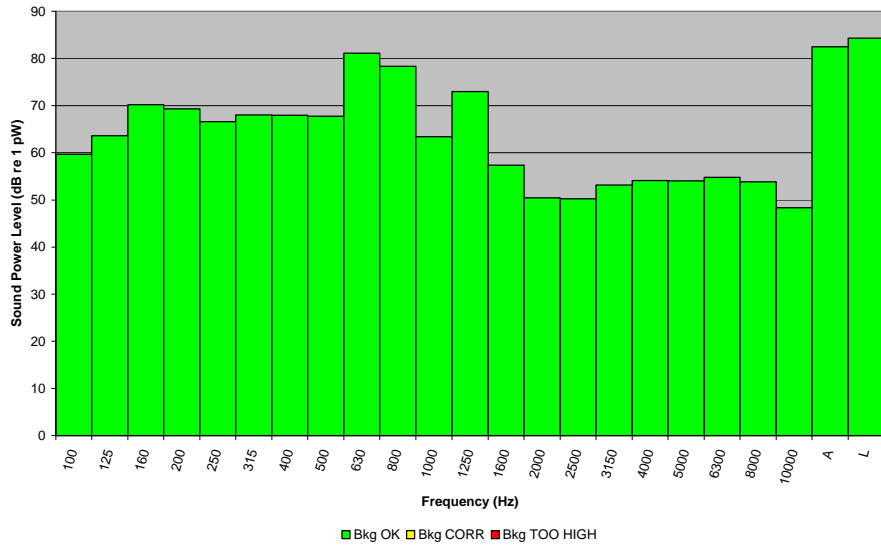
Tapper: Men's Sneaker on Concrete



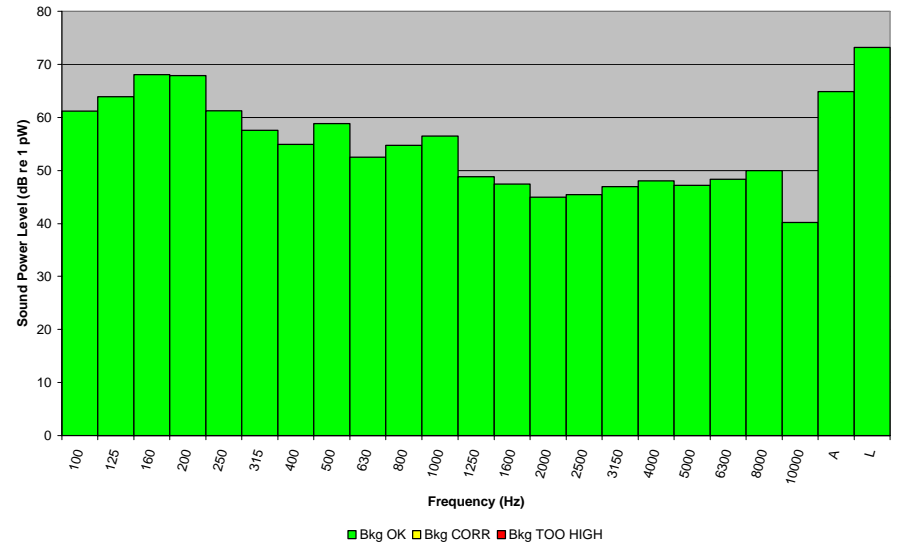
Tapper: Men's Rubber Sole on Concrete



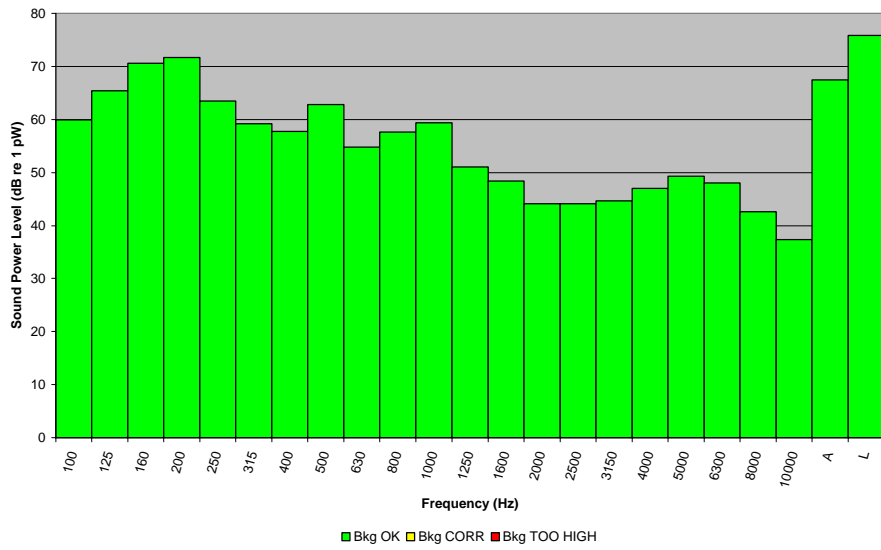
Tapper: Men's Leather Sole on Concrete



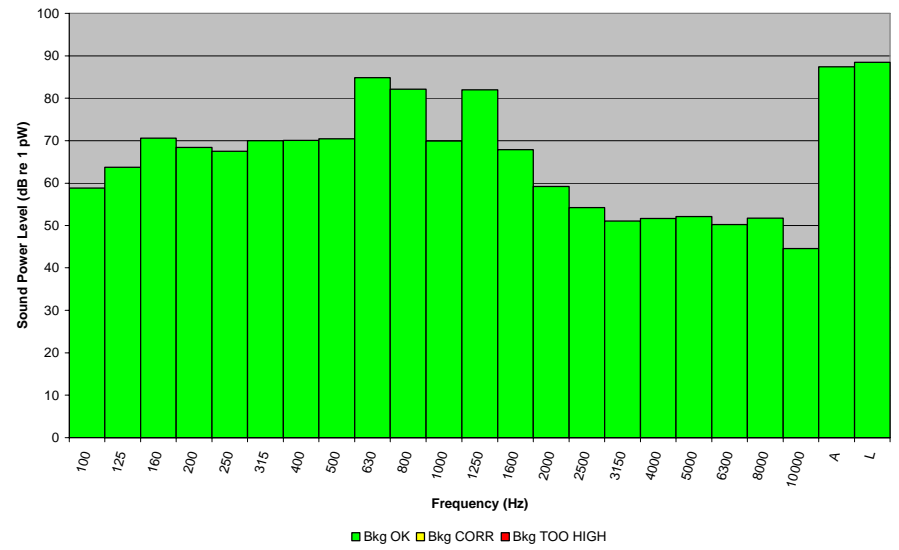
Tapper: Women's Sneaker on Concrete



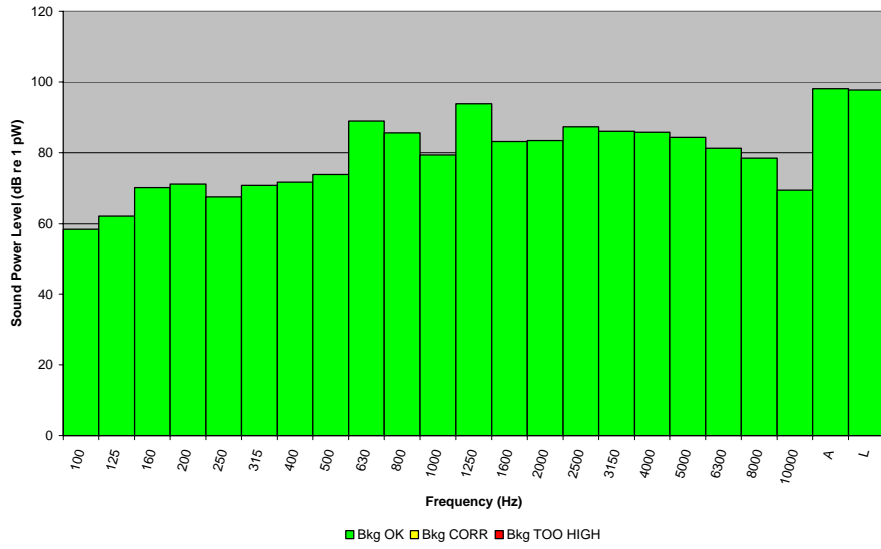
Tapper: Women's Rubber Sole on Concrete



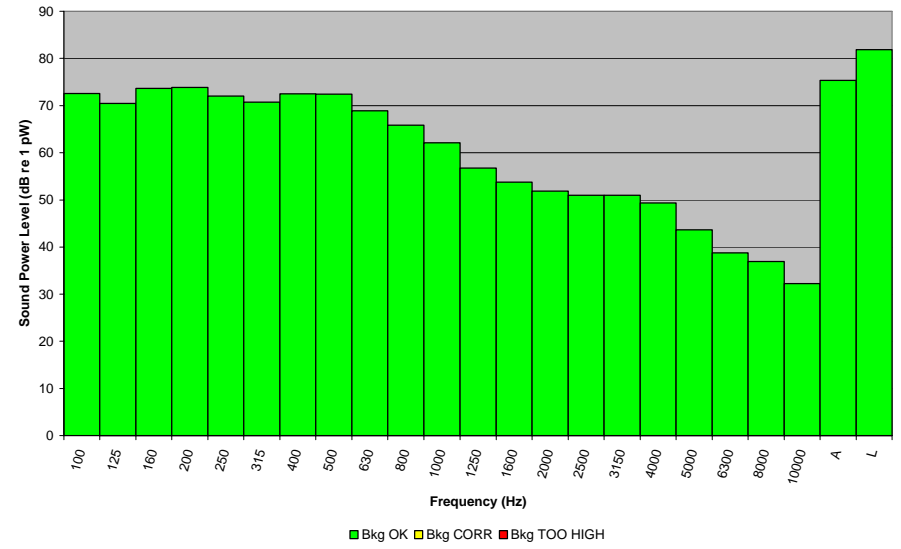
Tapper: Women's Leather Sole on Concrete



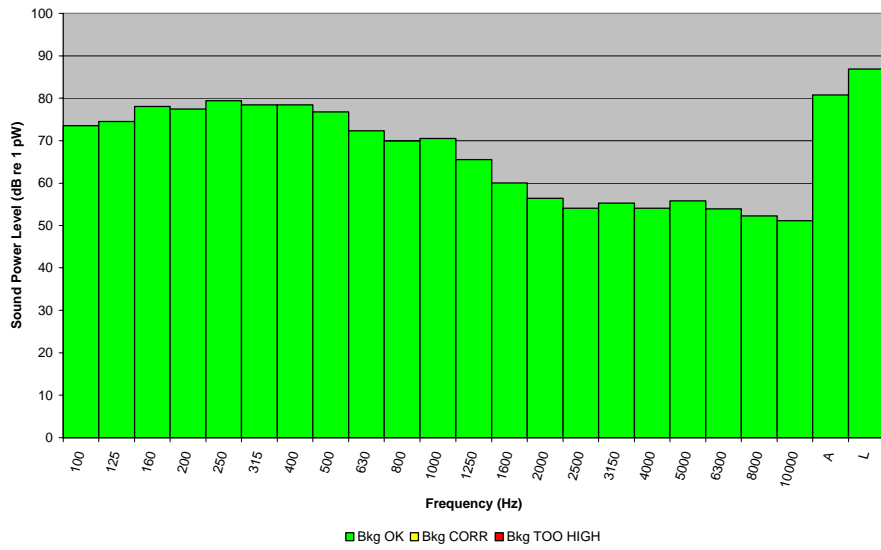
Bare Tapper on Concrete



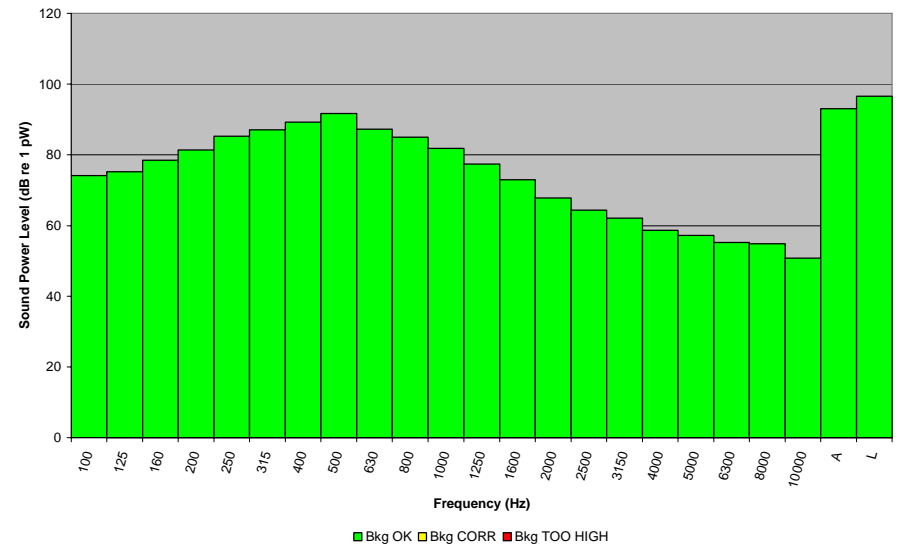
Tapper: Men's Sneaker on Sub-floor



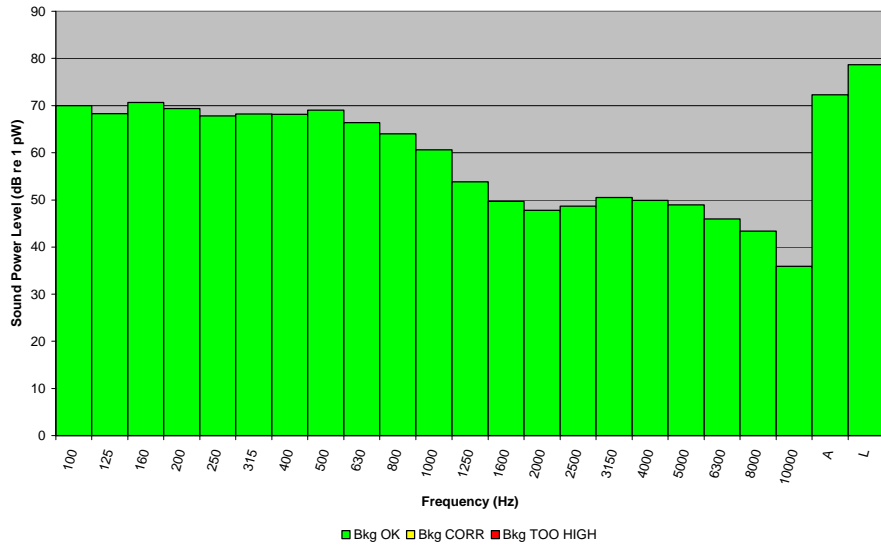
Tapper: Men's Rubber Sole on Sub-floor



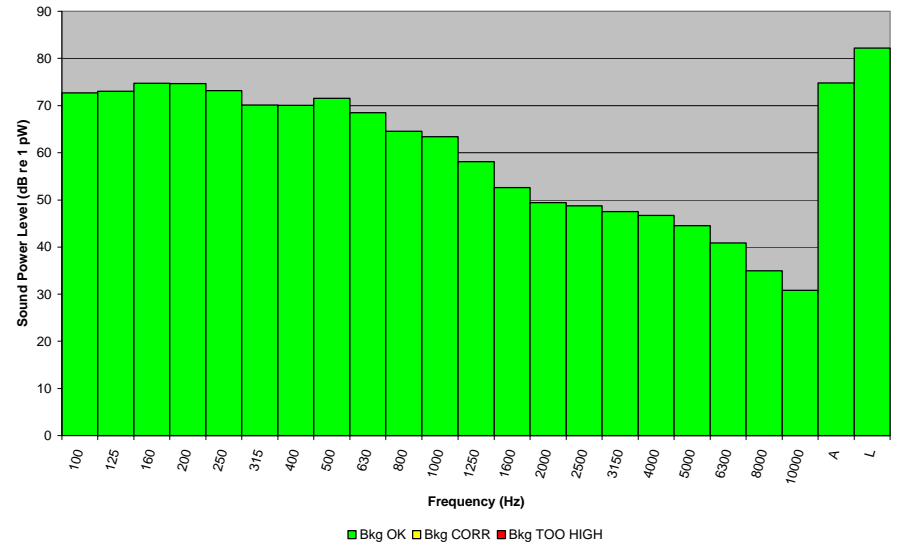
Tapper: Men's Leather Sole on Sub-floor



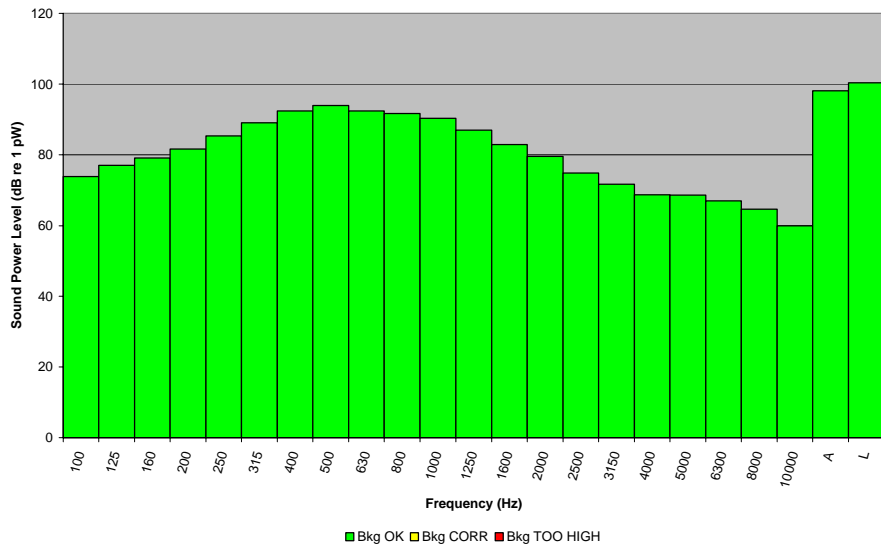
Tapper: Women's Sneaker on Sub-floor



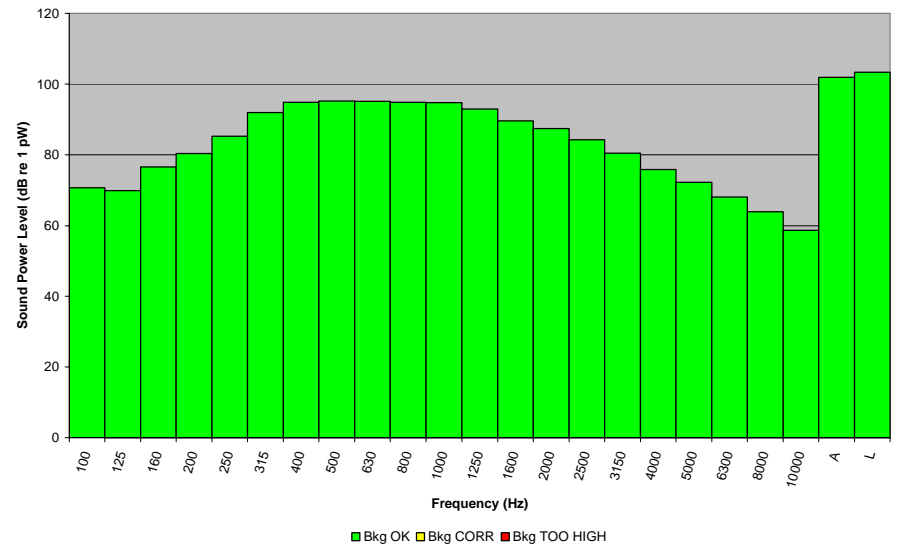
Tapper: Women's Rubber Sole on Sub-floor



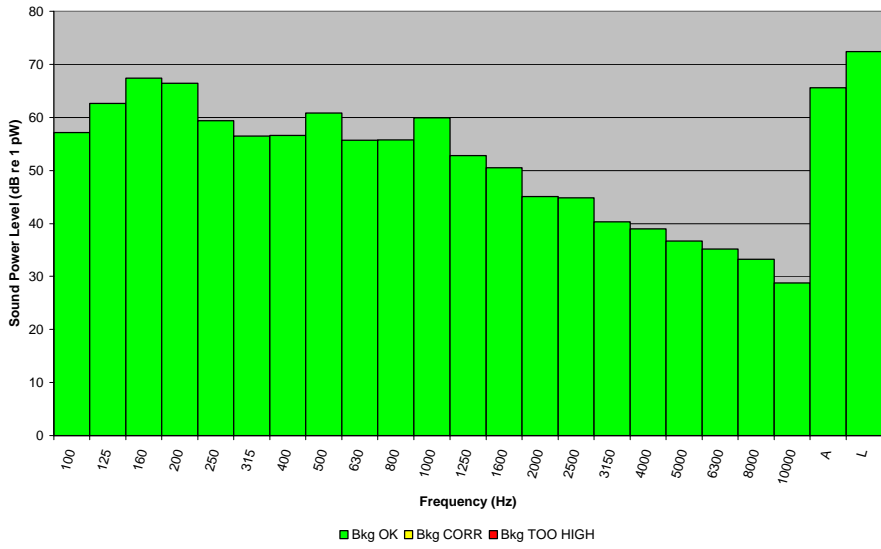
Tapper: Women's Leather Sole on Sub-floor



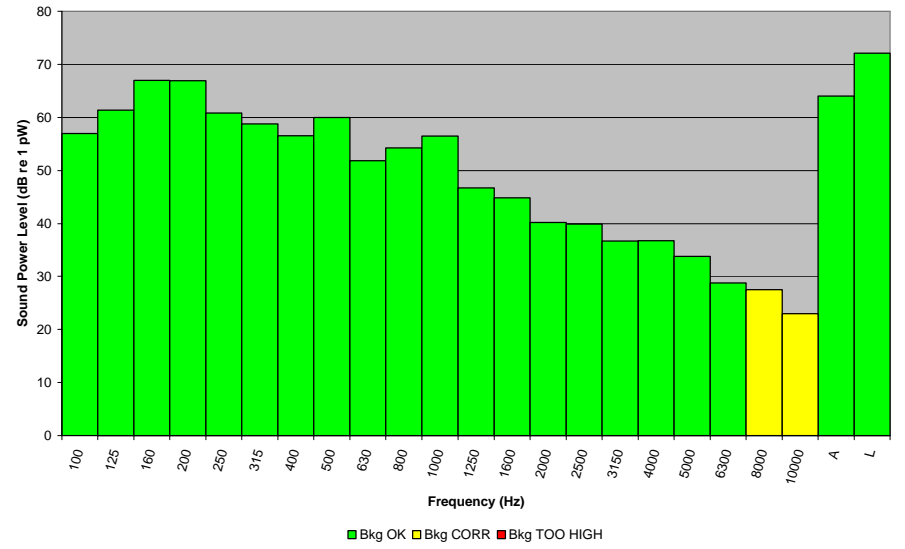
Bare Tapper on Sub-floor



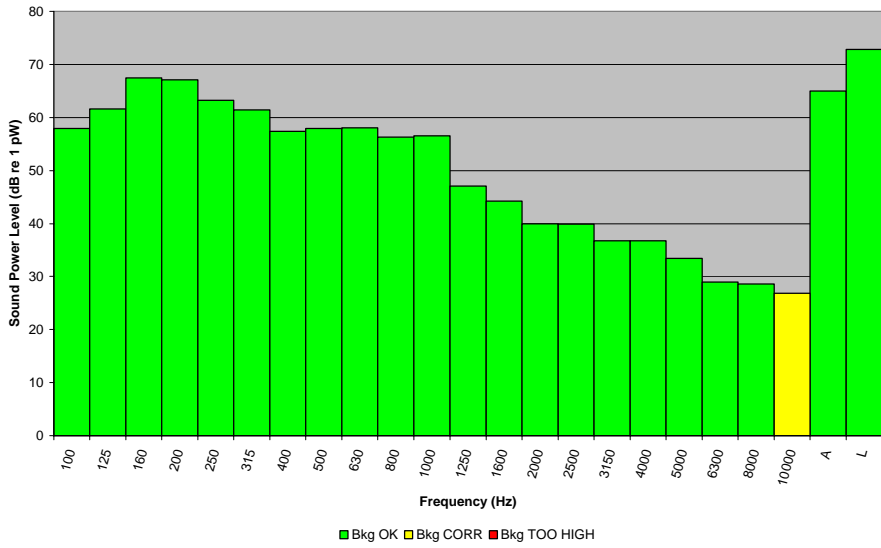
Tapper: Men's Sneaker on Carpet on Concrete



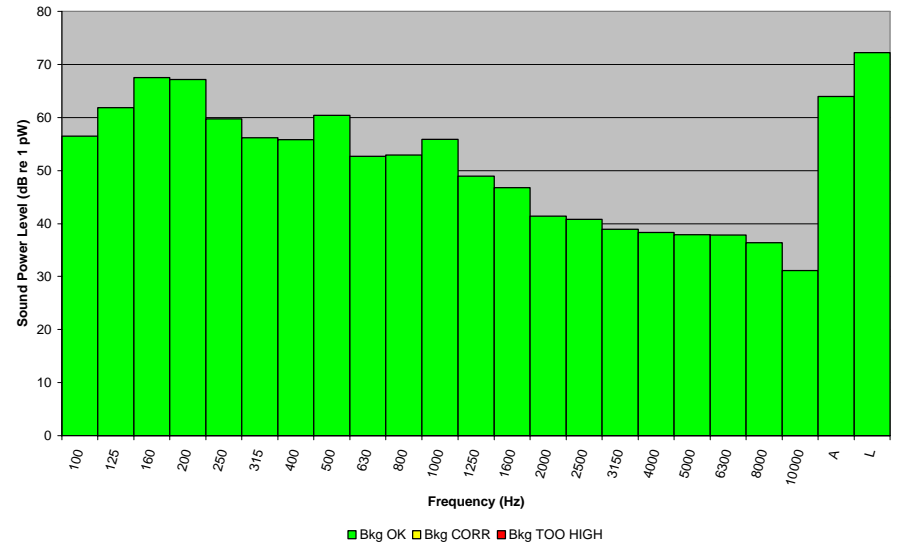
Tapper: Men's Rubber Sole on Carpet on Concrete



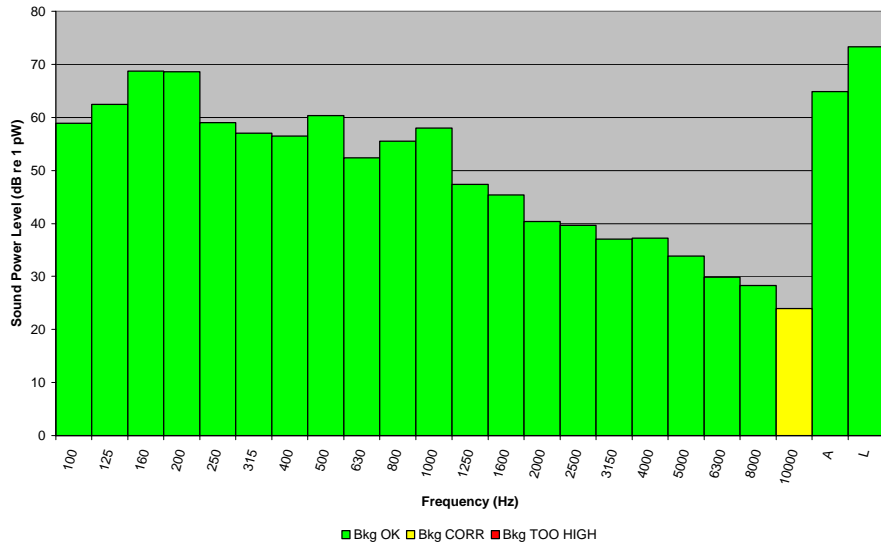
Tapper: Men's Leather Sole on Carpet on Concrete



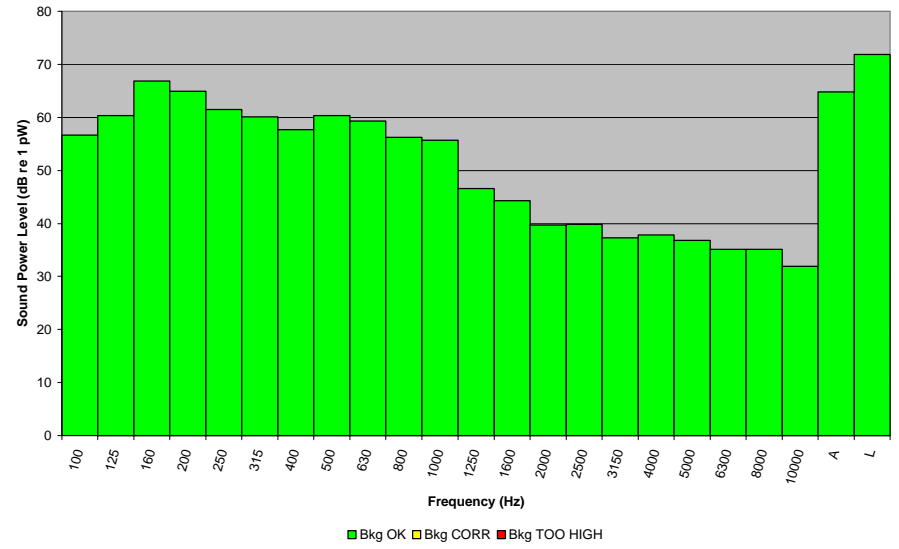
Tapper: Women's Sneaker on Carpet on Concrete



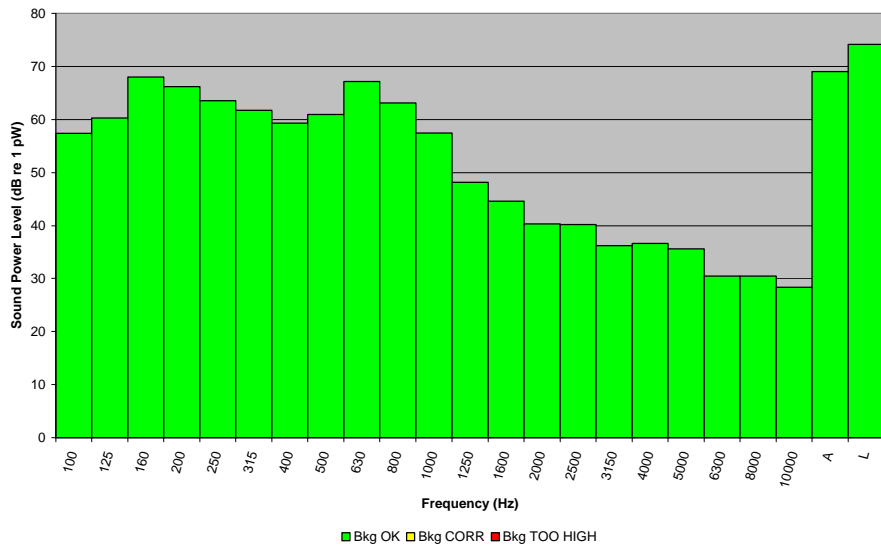
Tapper: Women's Rubber Sole on Carpet on Concrete



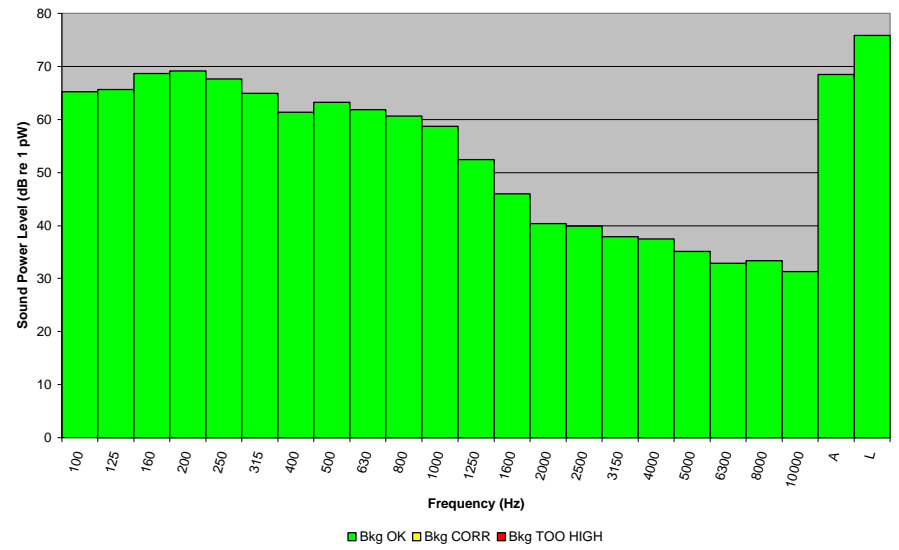
Tapper: Women's Leather Sole on Carpet on Concrete



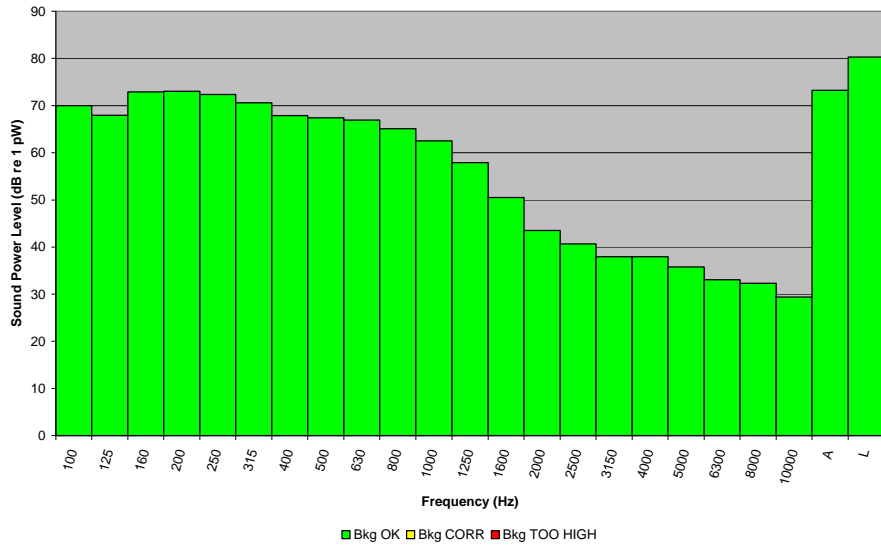
Bare Tapper on Carpet on Concrete



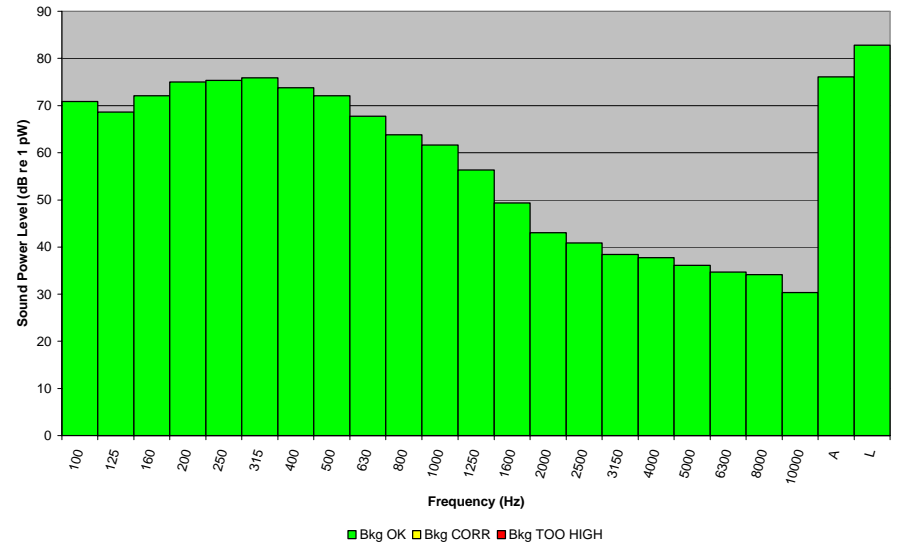
Tapper: Men's Sneaker on Carpet on Sub-floor



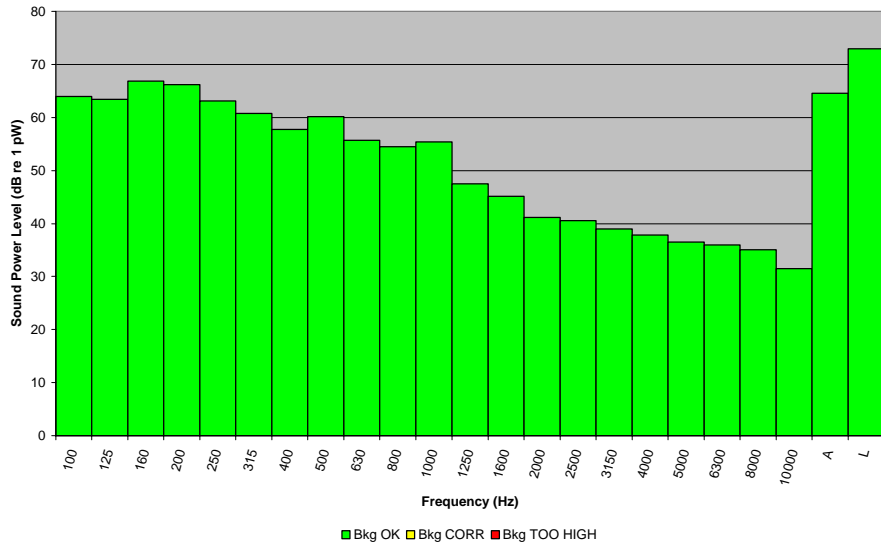
Tapper: Men's Rubber Sole on Carpet on Sub-floor



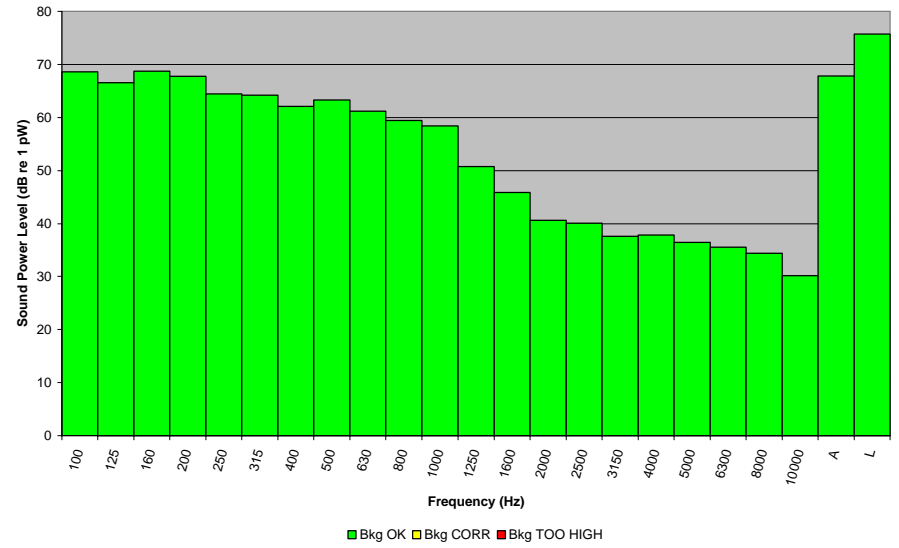
Tapper: Men's Leather Sole on Carpet on Sub-floor



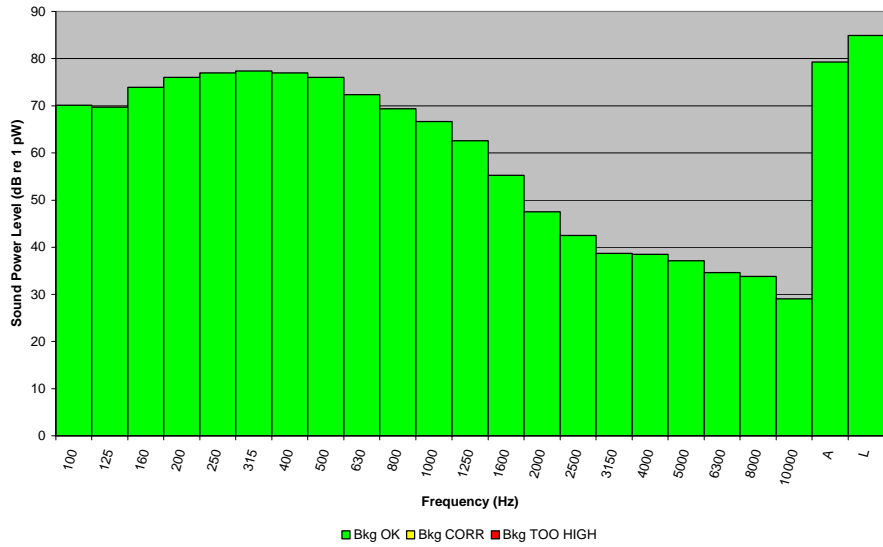
Tapper: Women's Sneaker on Carpet on Sub-floor



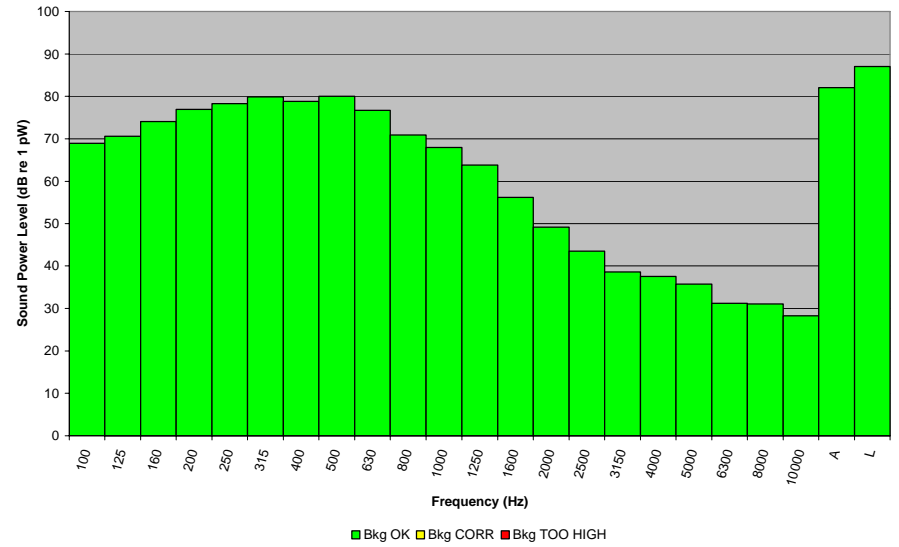
Tapper: Women's Rubber Sole on Carpet on Sub-floor



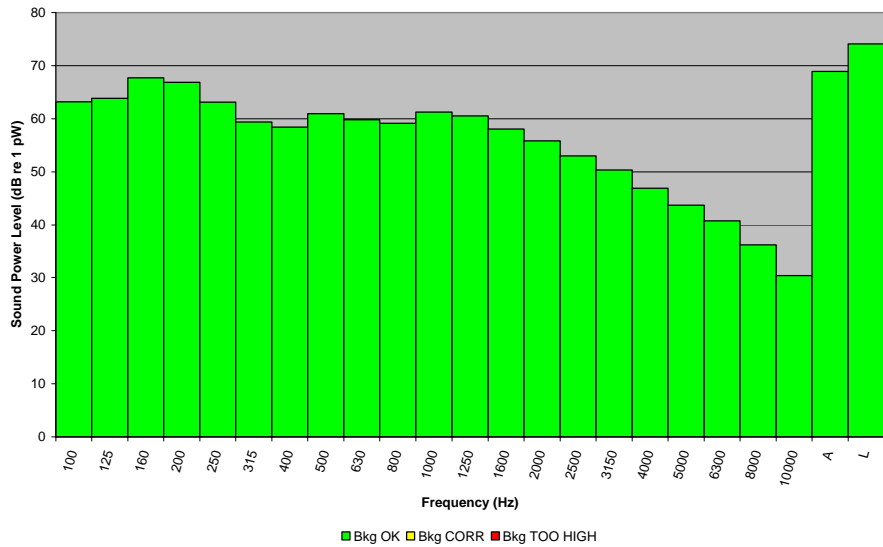
Tapper: Women's Leather Sole on Sub-floor



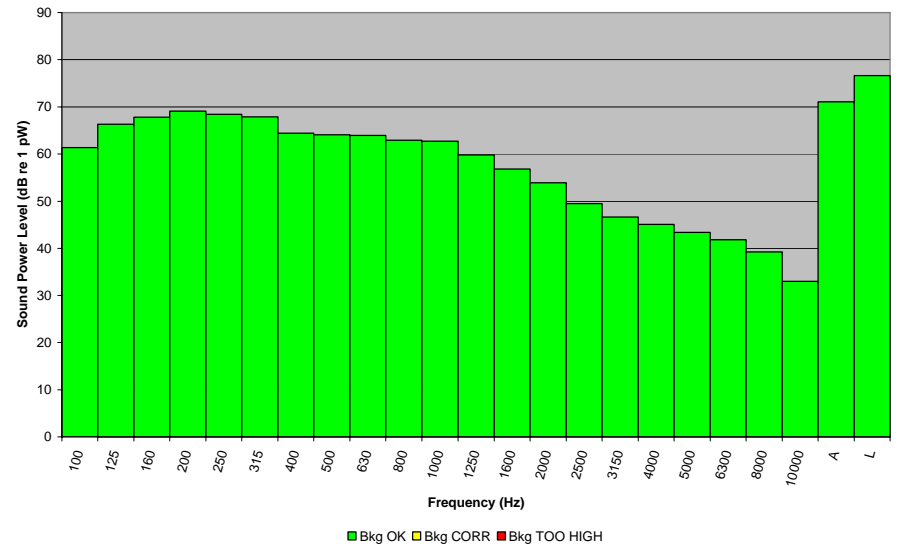
Bare Tapper on Carpet on Sub-floor



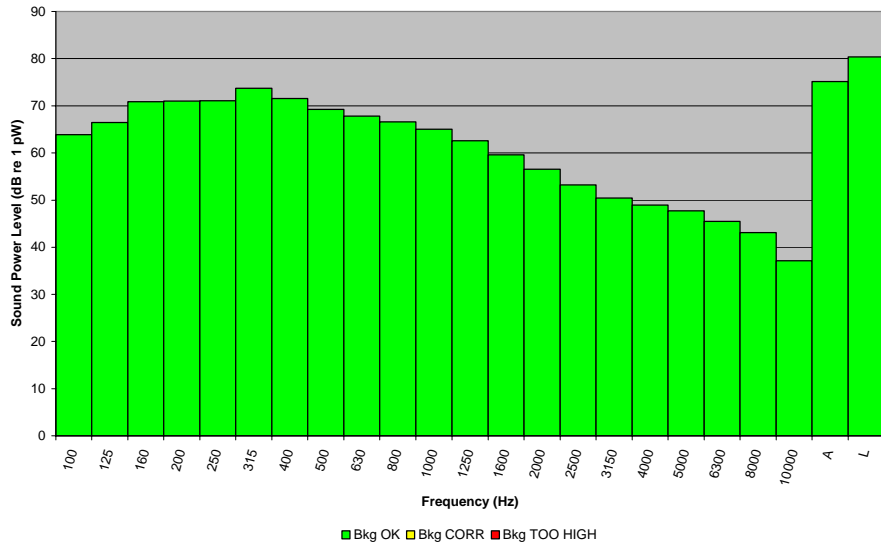
Tapper: Men's Sneaker on Wool Carpet



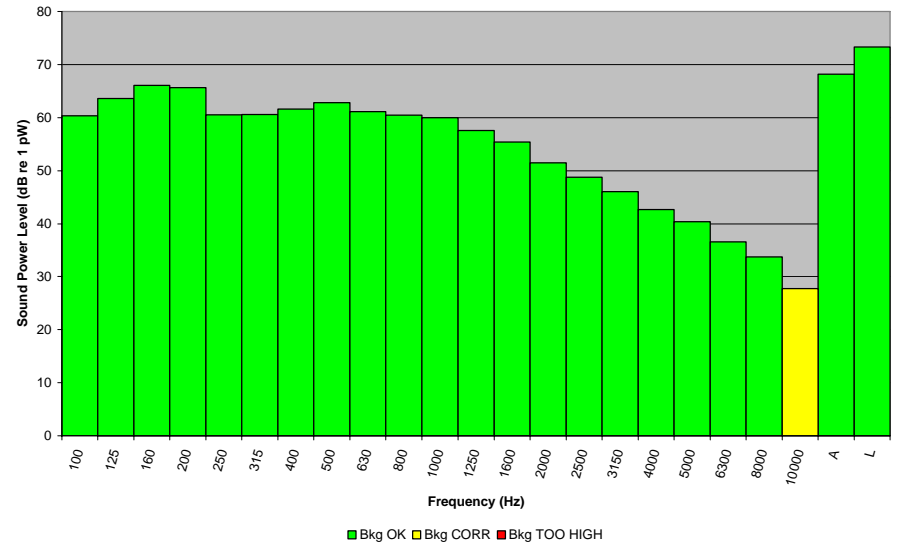
Tapper: Men's Rubber Sole on Wool Carpet



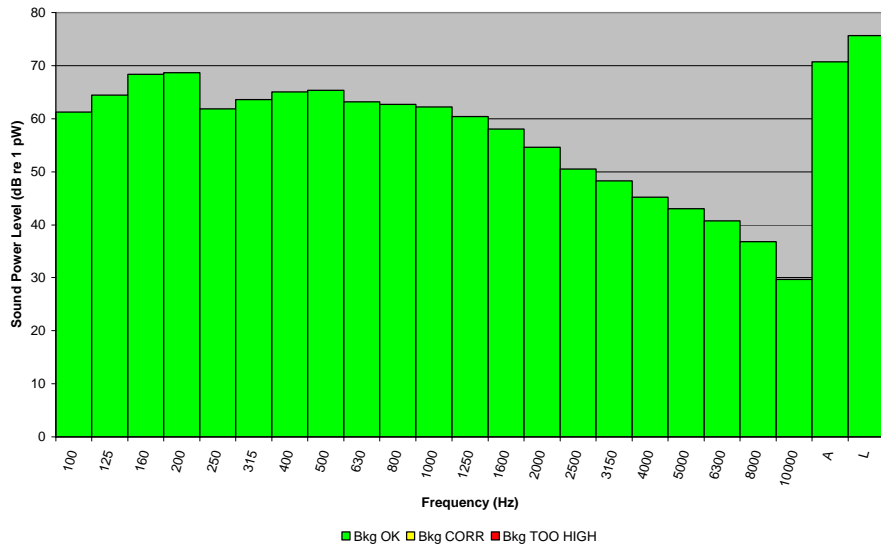
Tapper: Men's Leather Sole on Wool Carpet



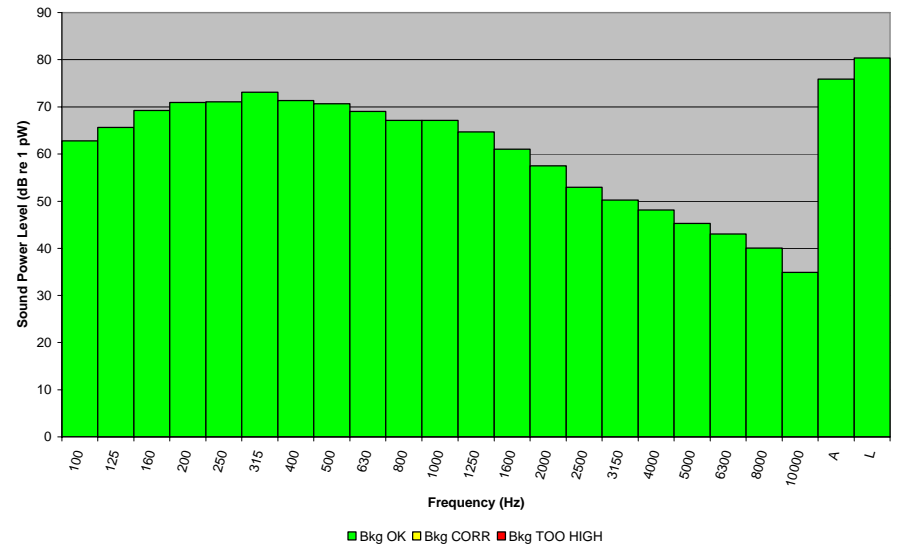
Tapper: Women's Sneaker on Wool Carpet



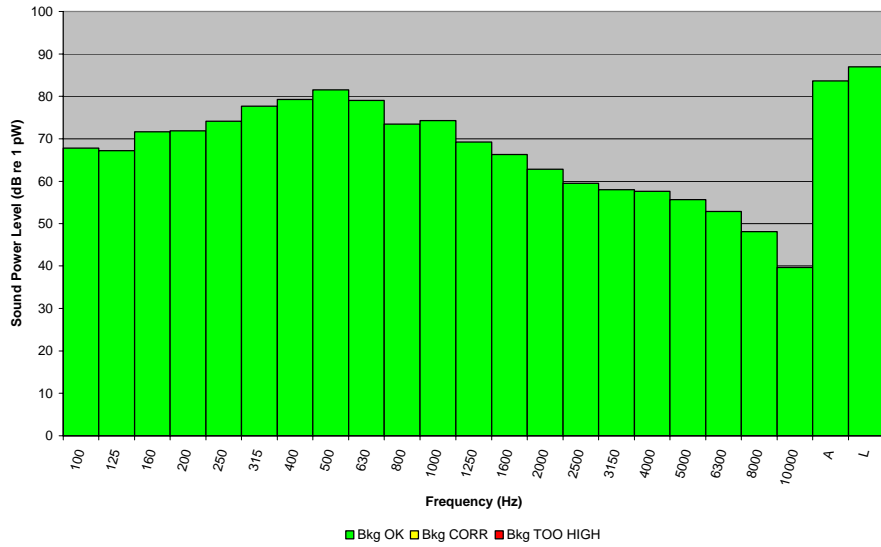
Tapper: Women's Rubber Sole on Wool Carpet



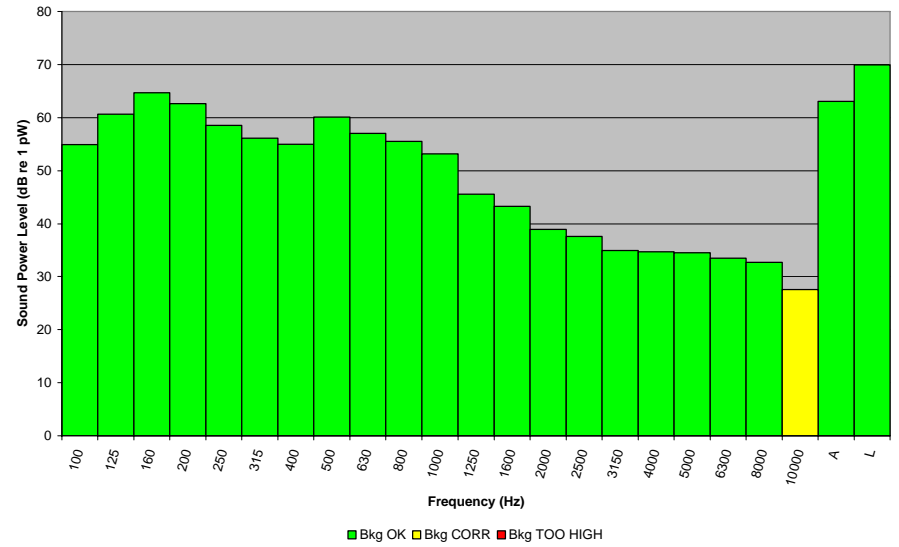
Tapper: Women's Leather Sole on Wool Carpet



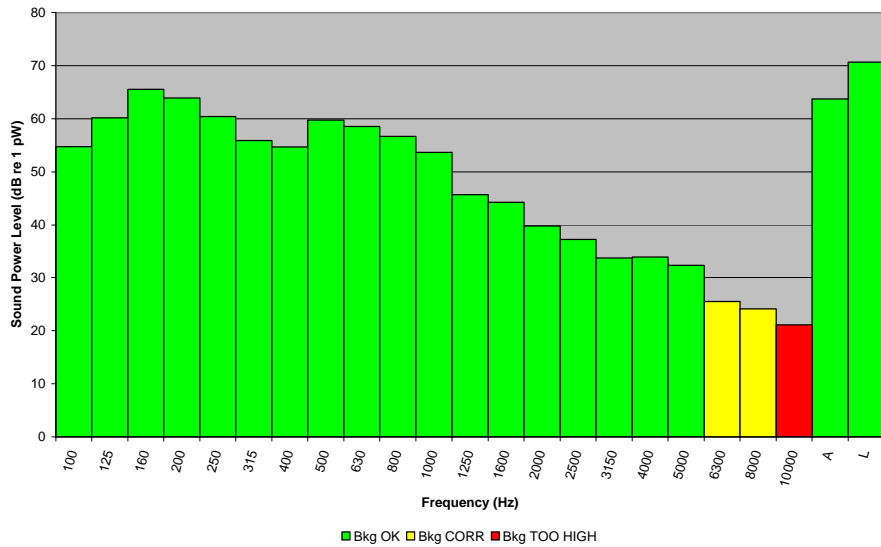
Bare Tapper on Wool Carpet



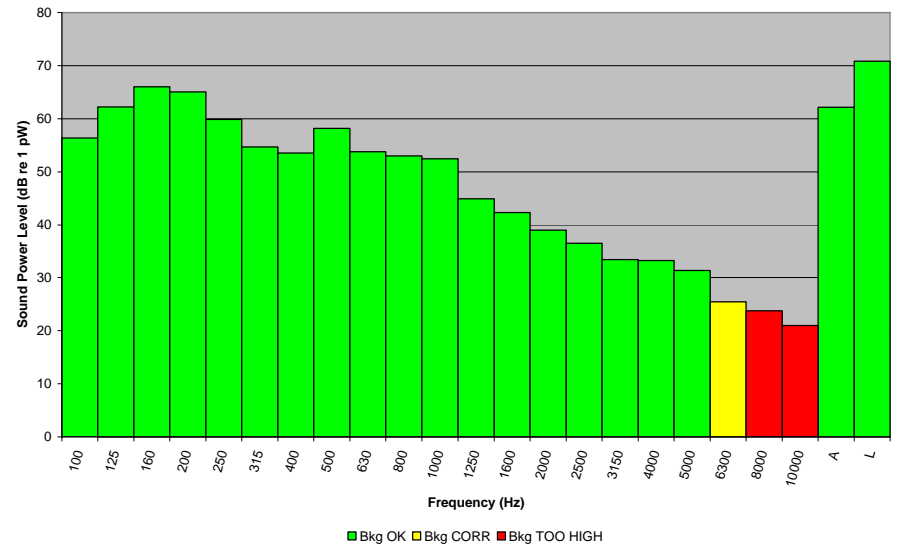
Tapper: Men's Sneaker on Wool Carpet with Pad



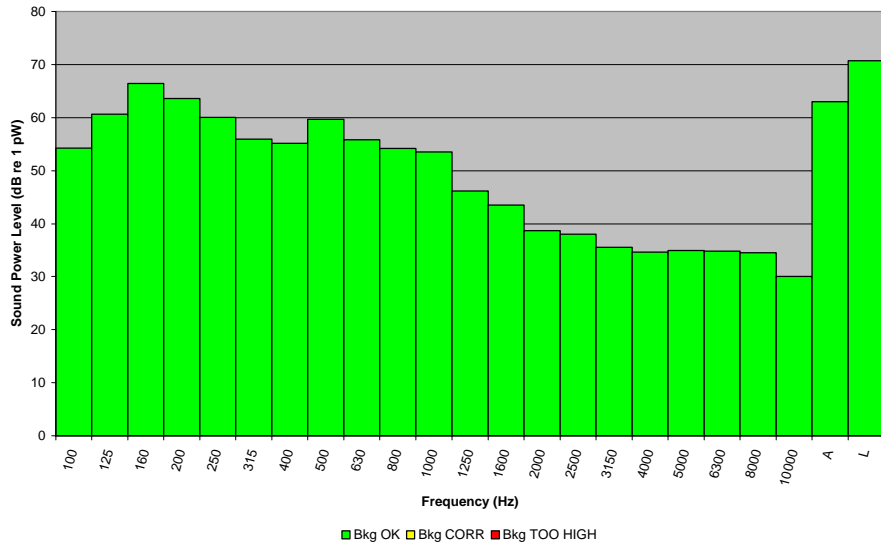
Tapper: Men's Rubber Sole on Wool Carpet with Pad



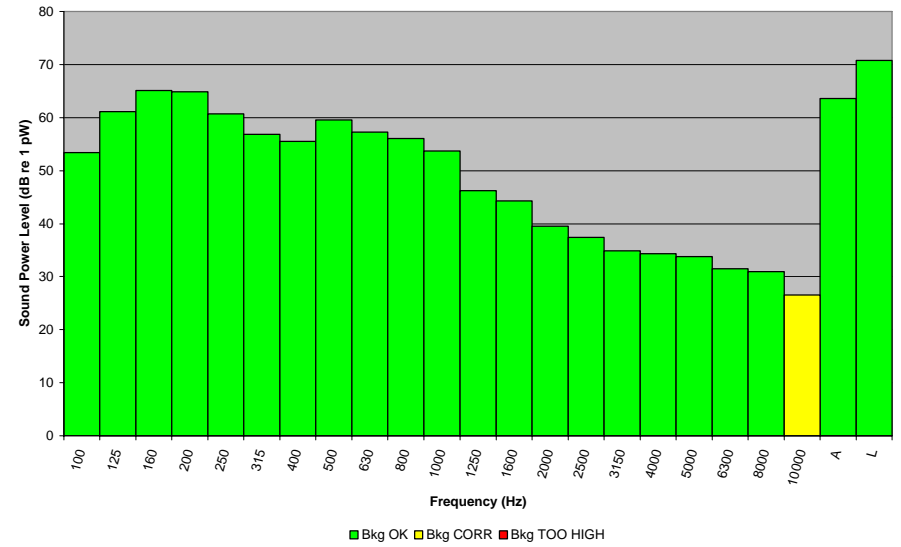
Tapper: Men's Leather Sole on Wool Carpet with Pad



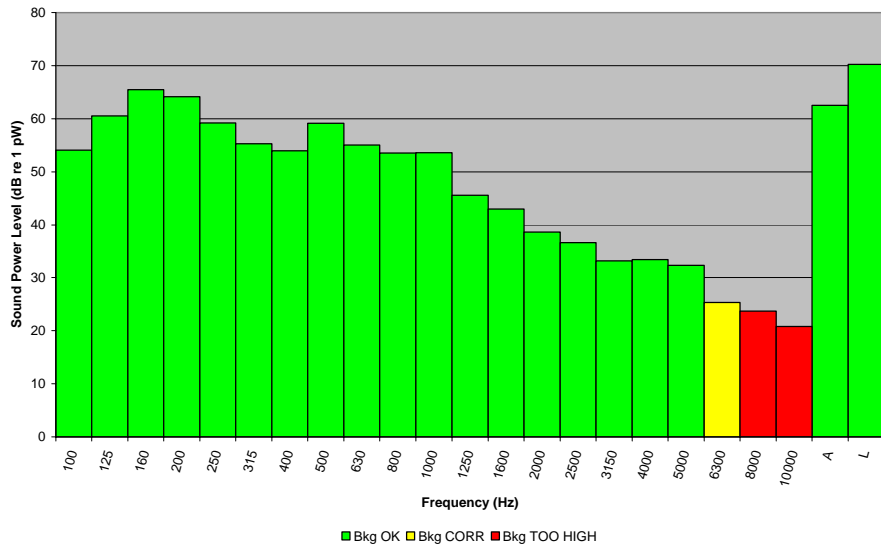
Tapper: Women's Sneaker on Wool Carpet with Pad



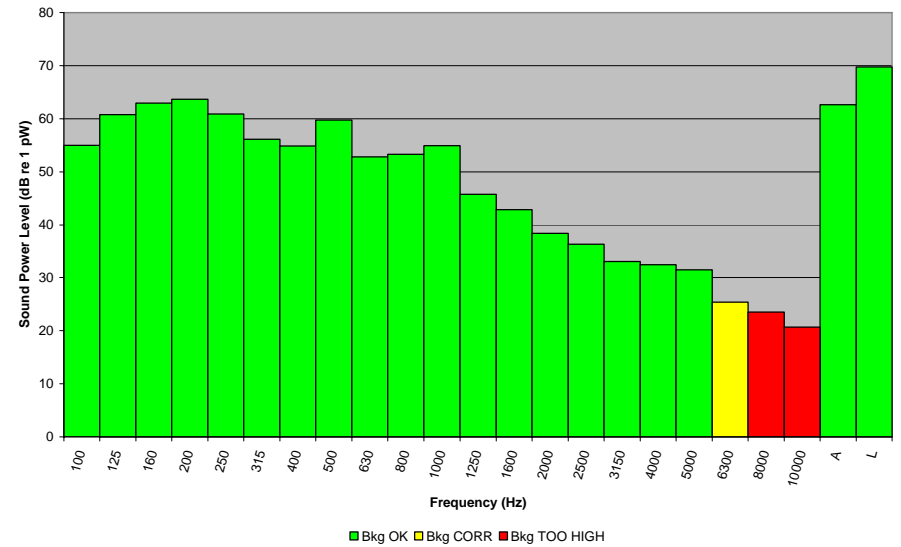
Tapper: Women's Rubber Sole on Wool Carpet with Pad



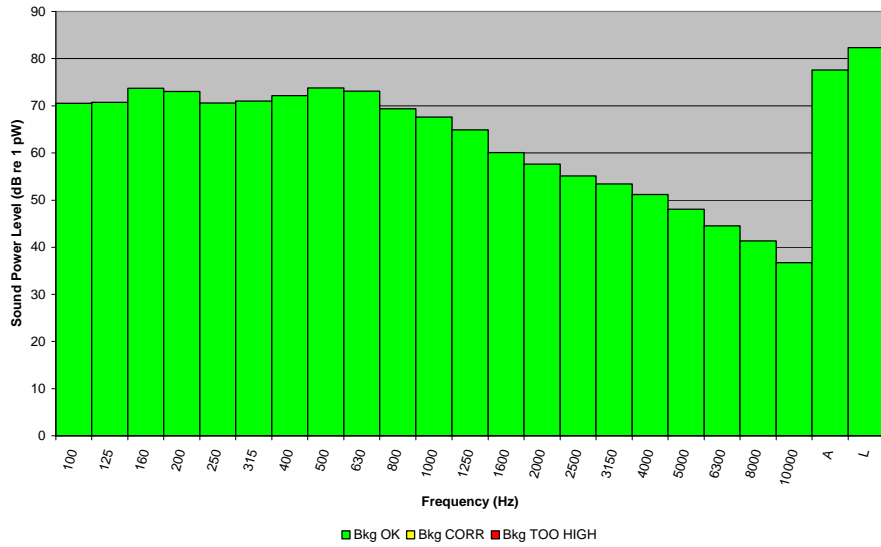
Tapper: Women's Leather Sole on Wool Carpet with Pad



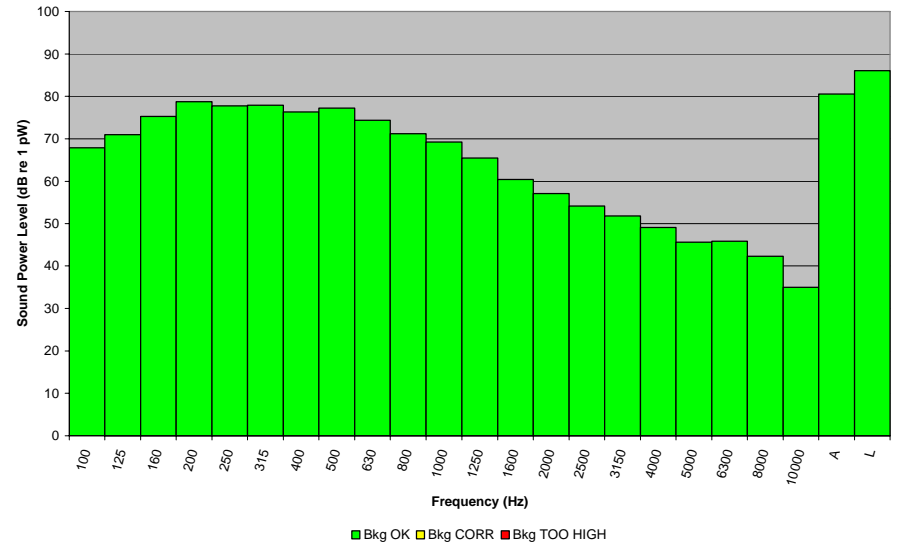
Bare Tapper on Wool Carpet with Pad



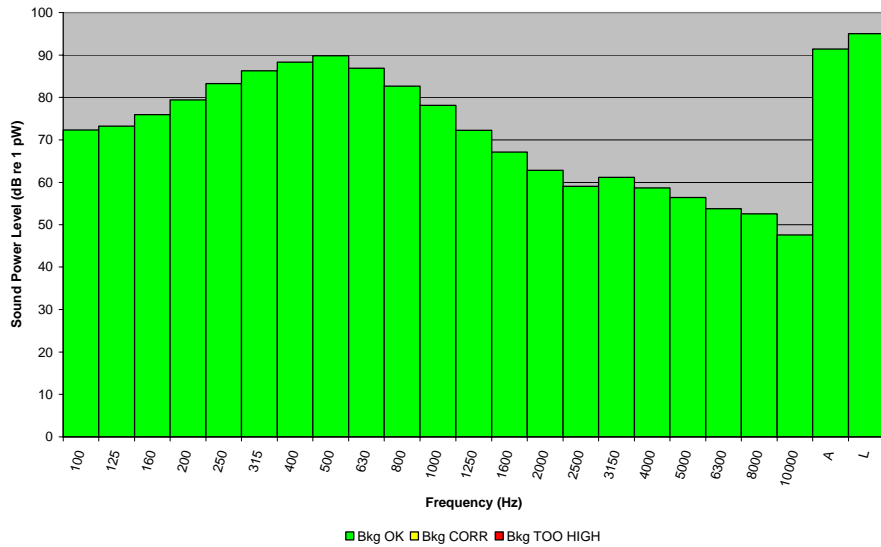
Tapper: Men's Sneaker on Thin Vinyl



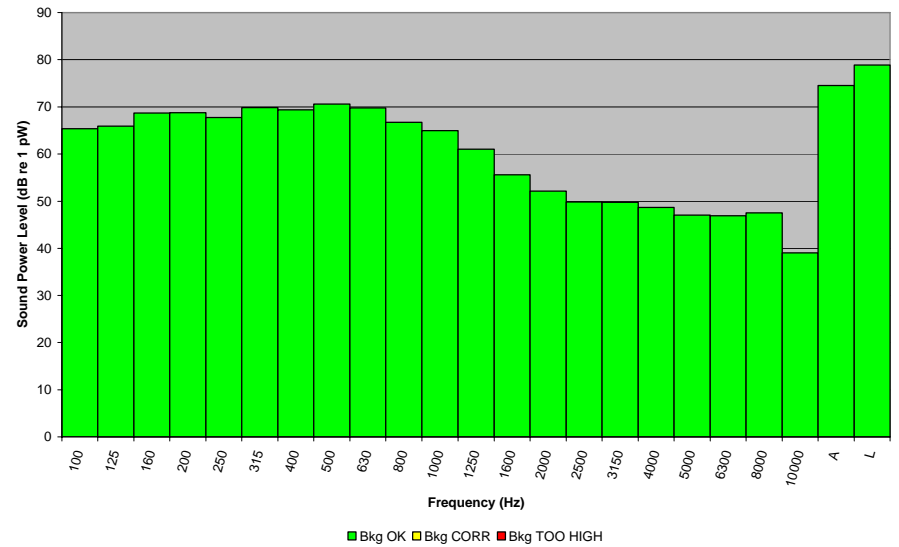
Tapper: Men's Rubber Sole on Thin Vinyl



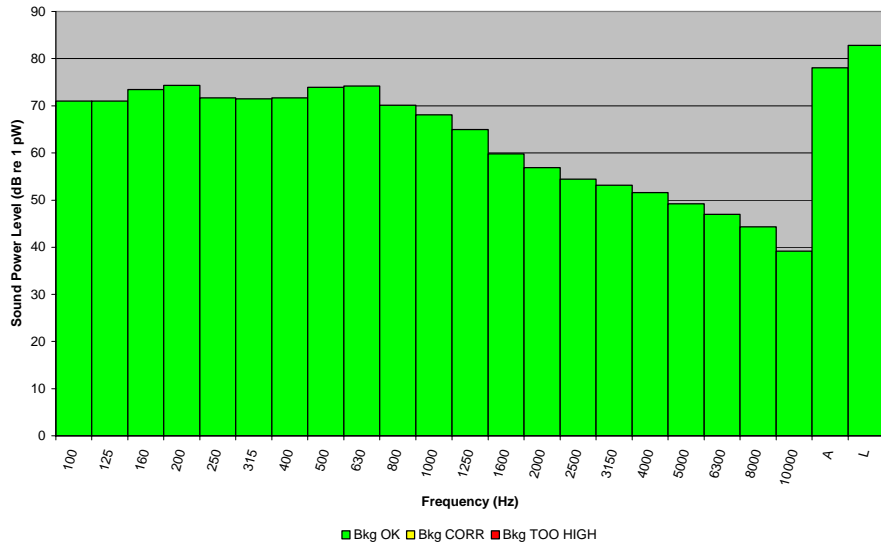
Tapper: Men's Leather Sole on Thin Vinyl



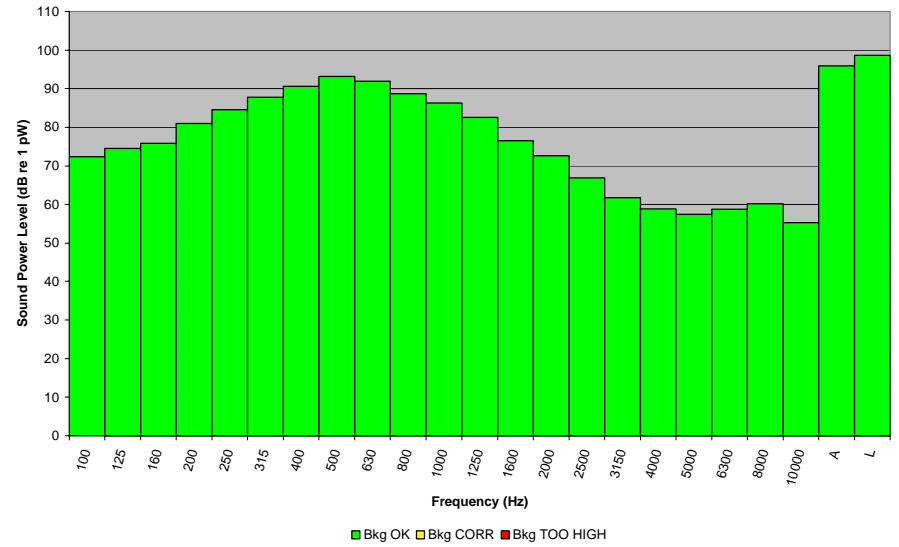
Tapper: Women's Sneaker on Thin Vinyl



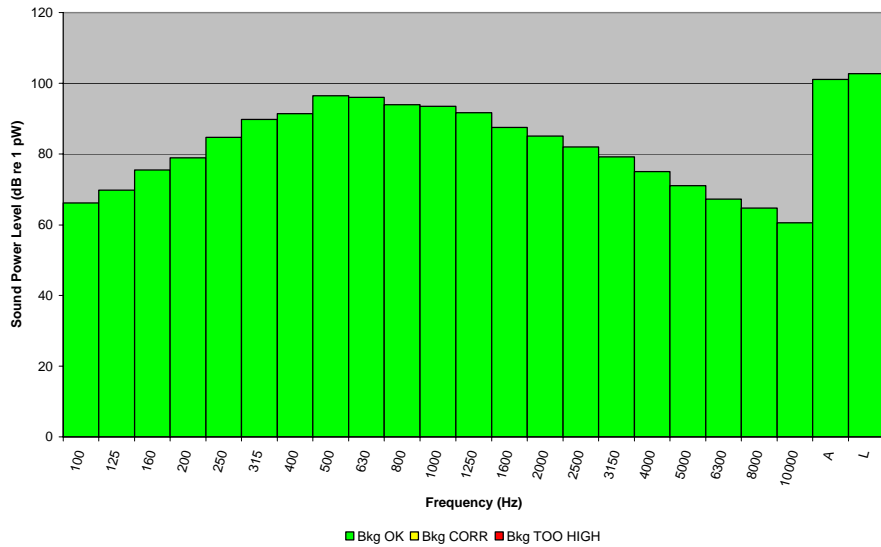
Tapper: Women's Rubber Sole on Thin Vinyl



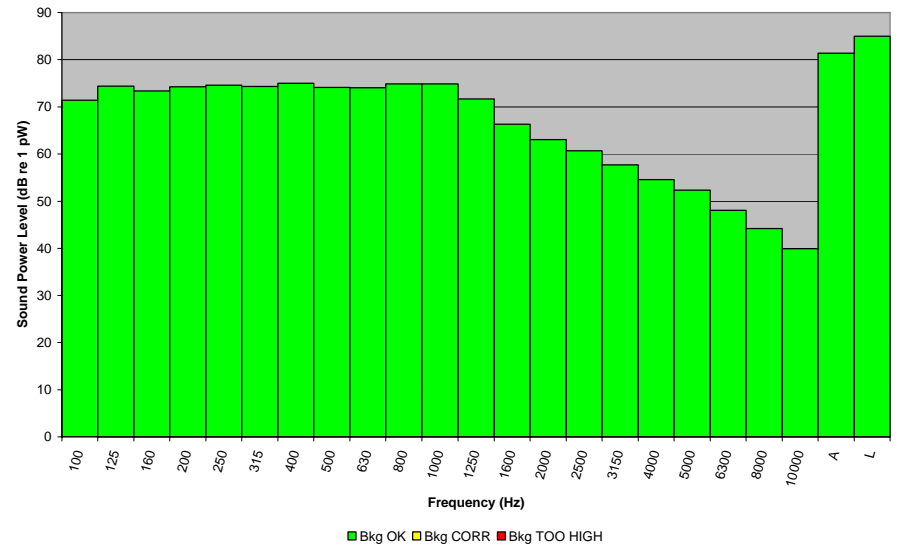
Tapper: Women's Leather Sole on Thin Vinyl



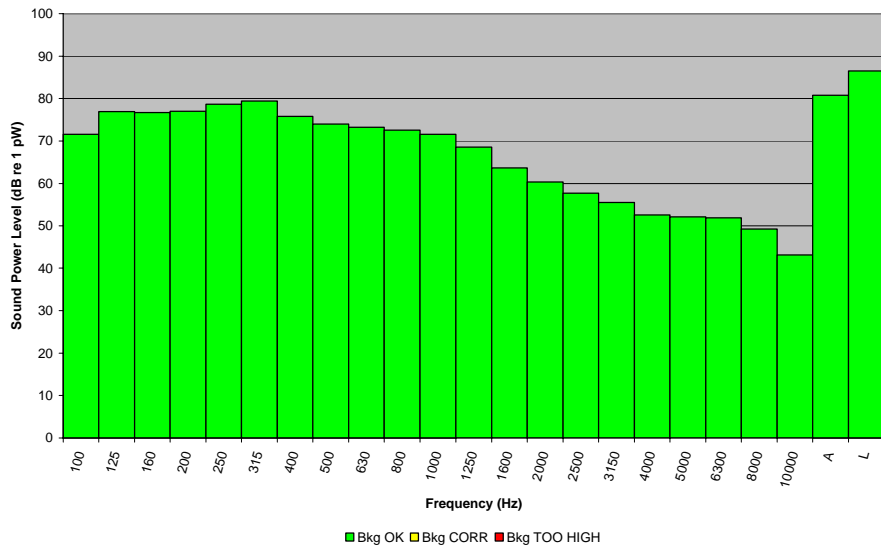
Bare Tapper on Thin Vinyl



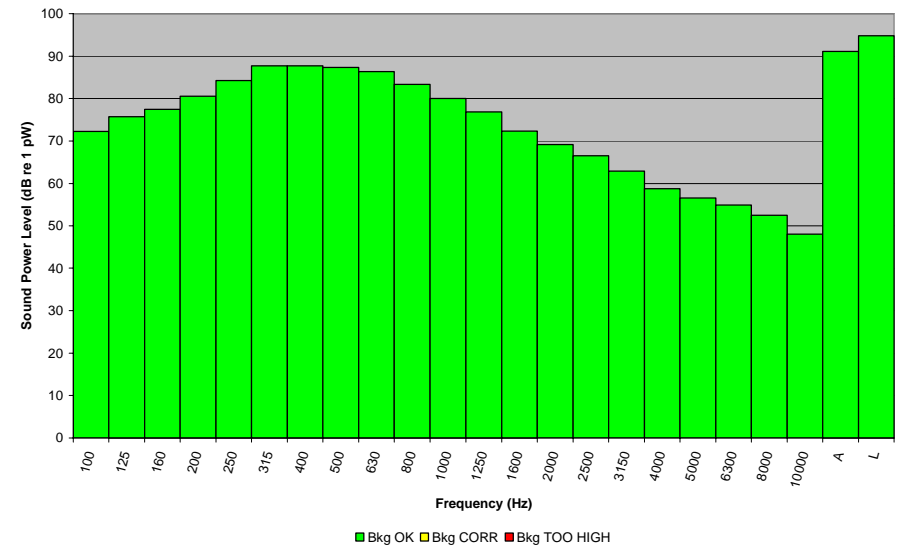
Tapper: Men's Sneaker on Medium Vinyl



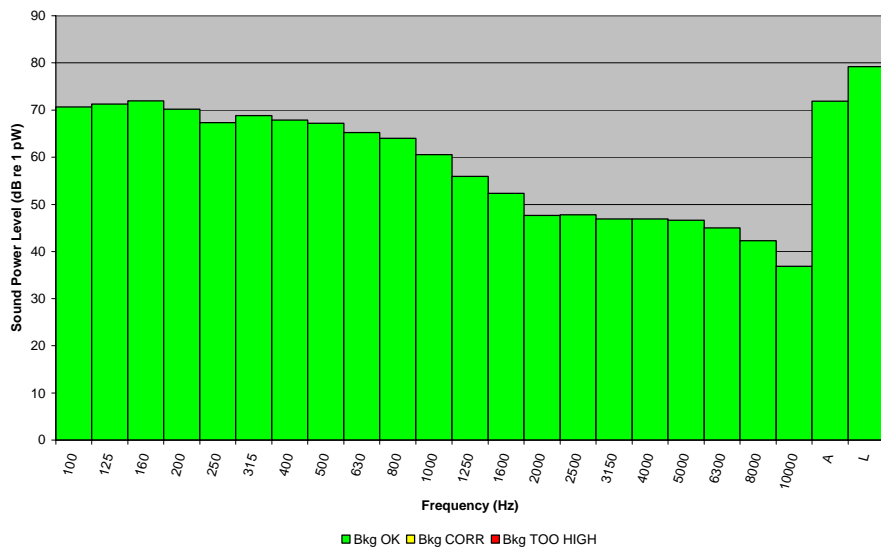
Tapper: Men's Rubber Sole on Medium Vinyl



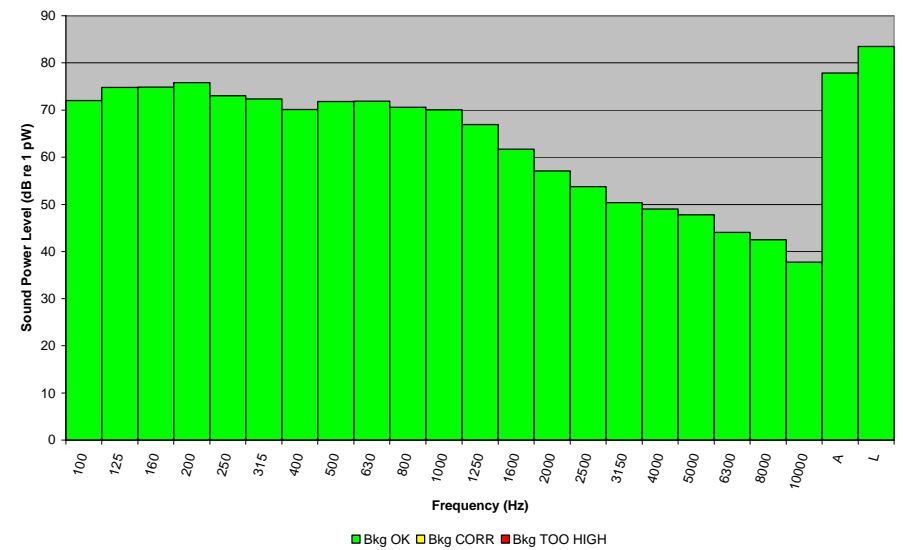
Tapper: Men's Leather Sole on Medium Vinyl



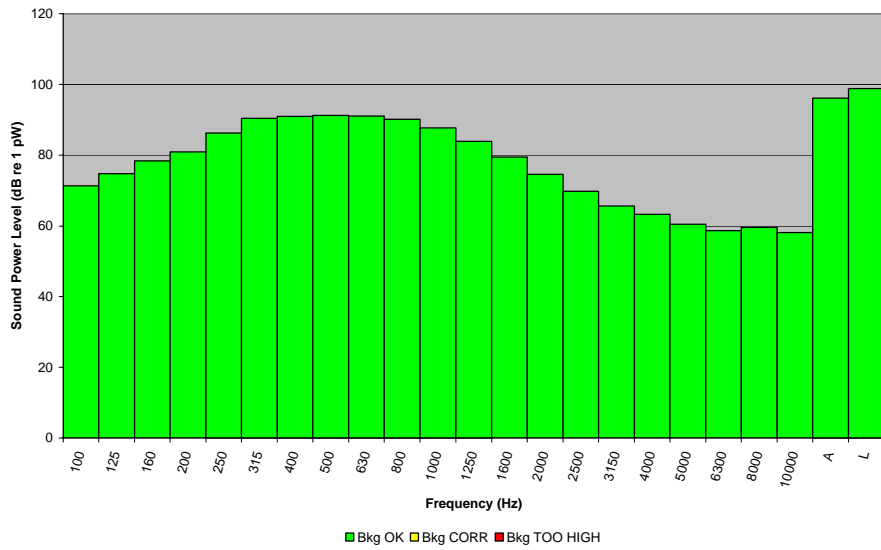
Tapper: Women's Sneaker on Medium Vinyl



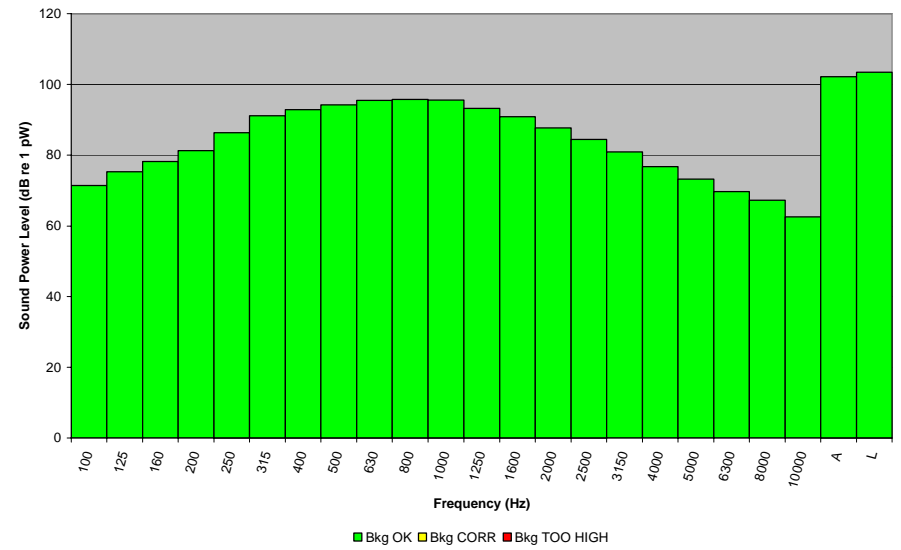
Tapper: Women's Rubber Sole on Medium Vinyl



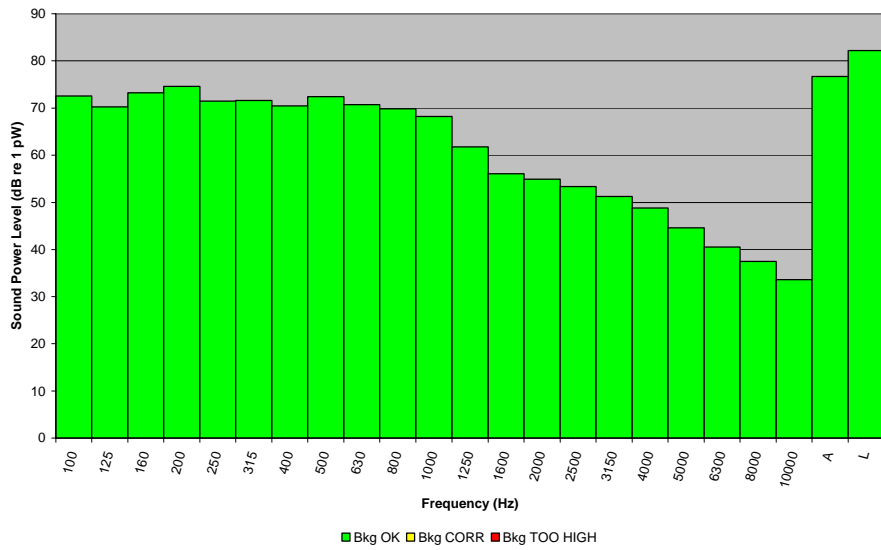
Tapper: Women's Leather Sole on Medium Vinyl



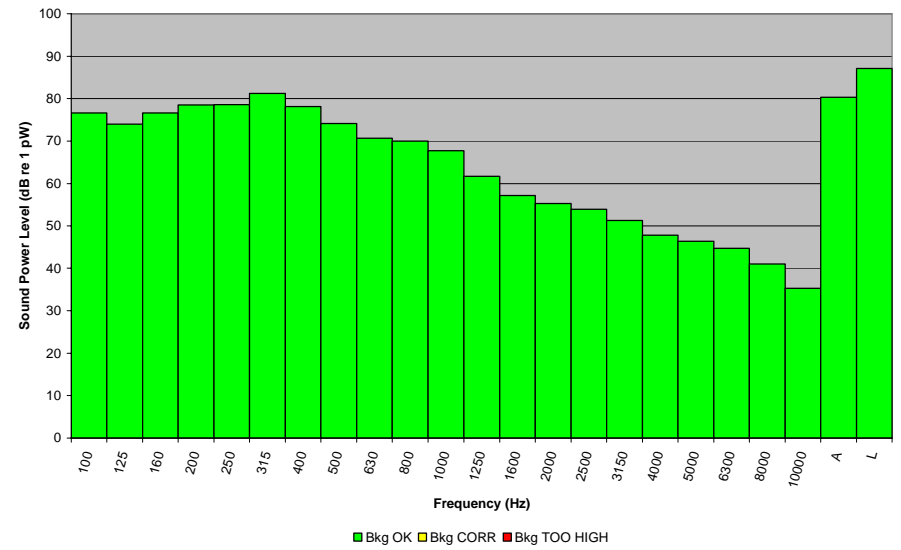
Bare Tapper on Medium Vinyl



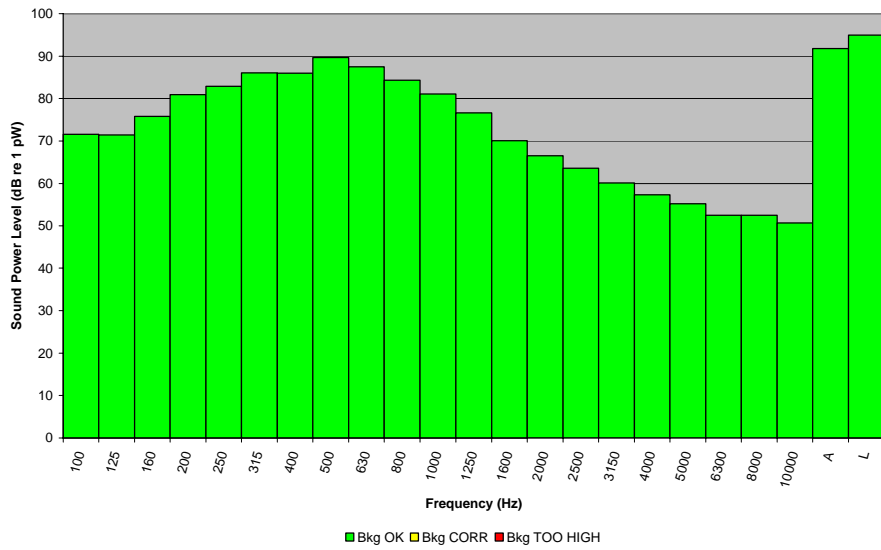
Tapper: Men's Sneaker on Thick Vinyl



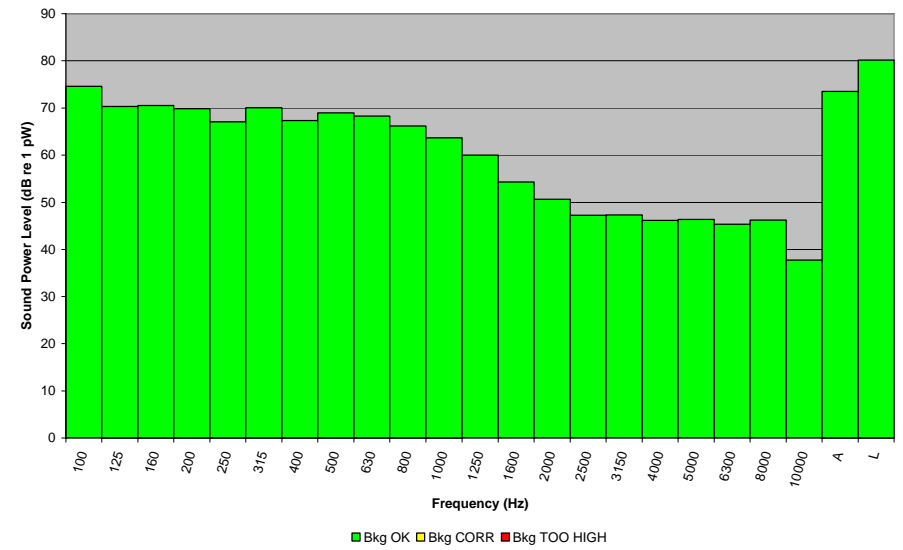
Tapper: Men's Rubber Sole on Thick Vinyl



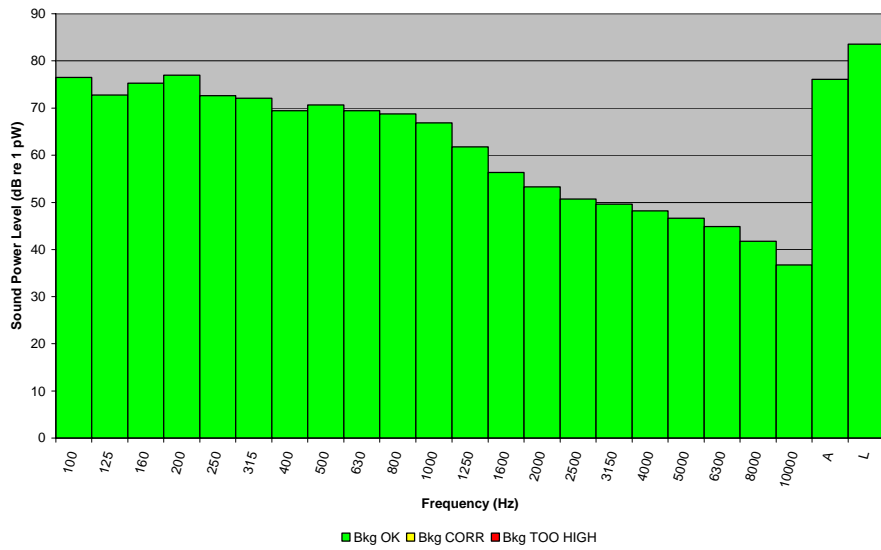
Tapper: Men's Leather Sole on Thick Vinyl



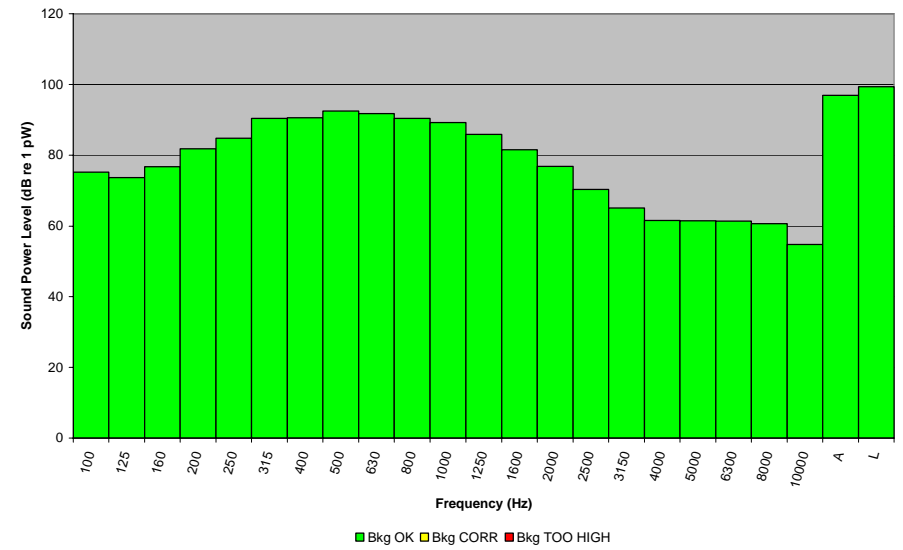
Tapper: Women's Sneaker on Thick Vinyl



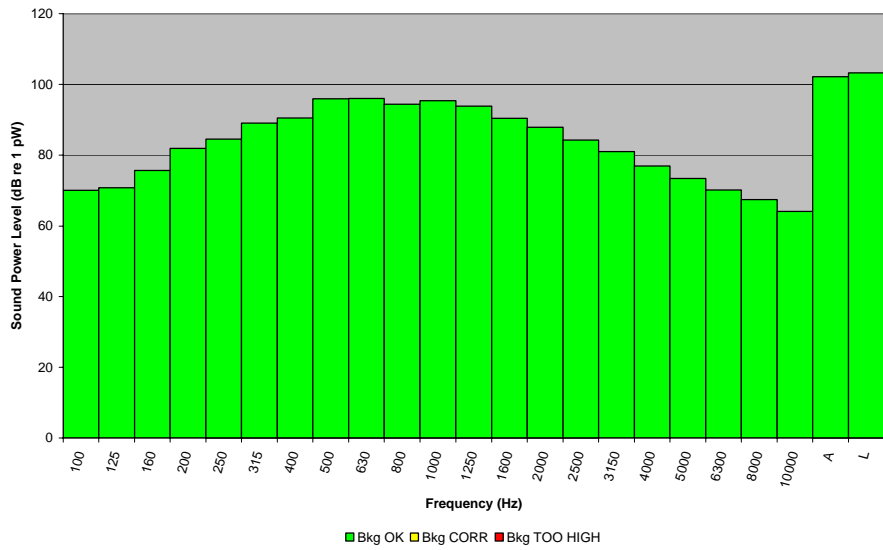
Tapper: Women's Rubber Sole on Thick Vinyl



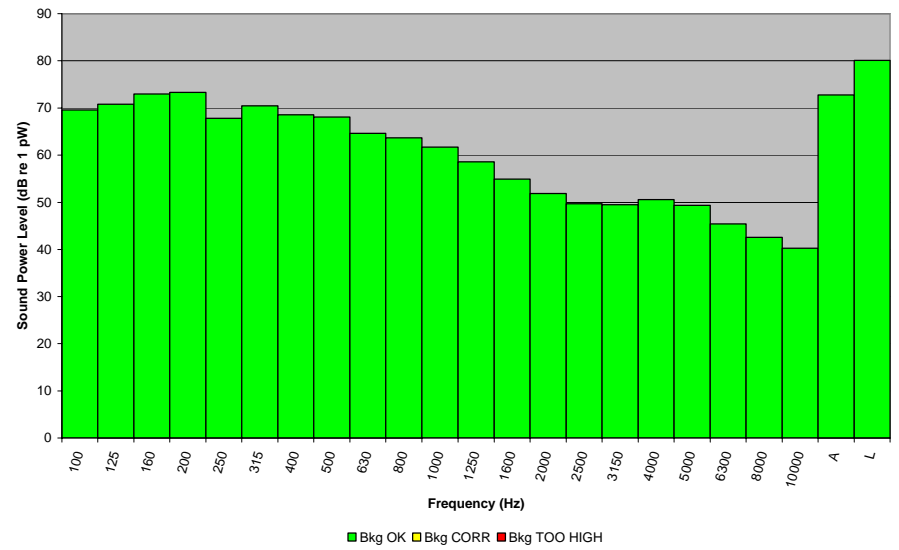
Tapper: Women's Leather Sole on Thick Vinyl



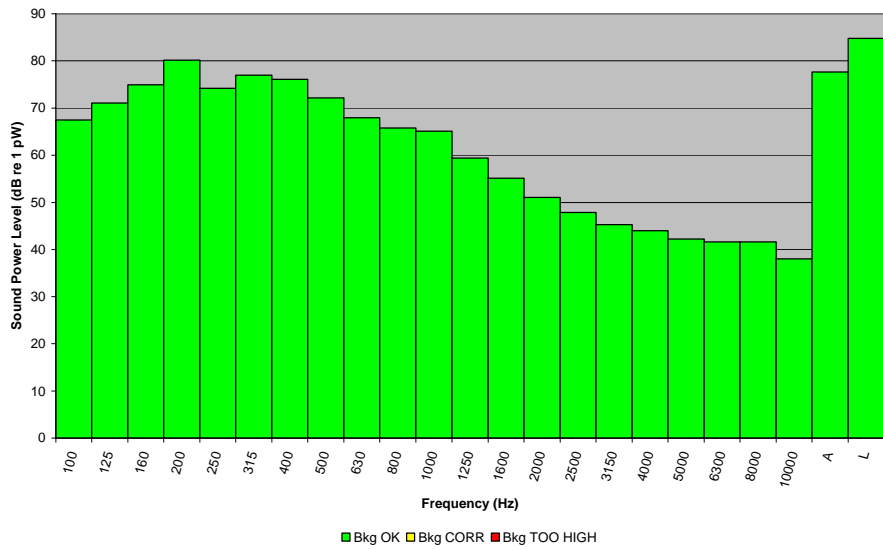
Bare Tapper on Thick Vinyl



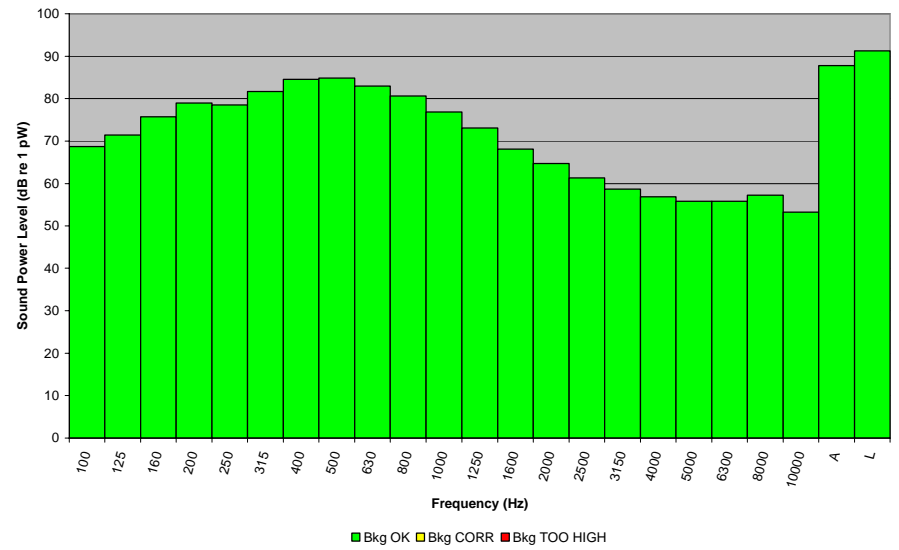
Tapper: Men's Sneaker on Oak Floor



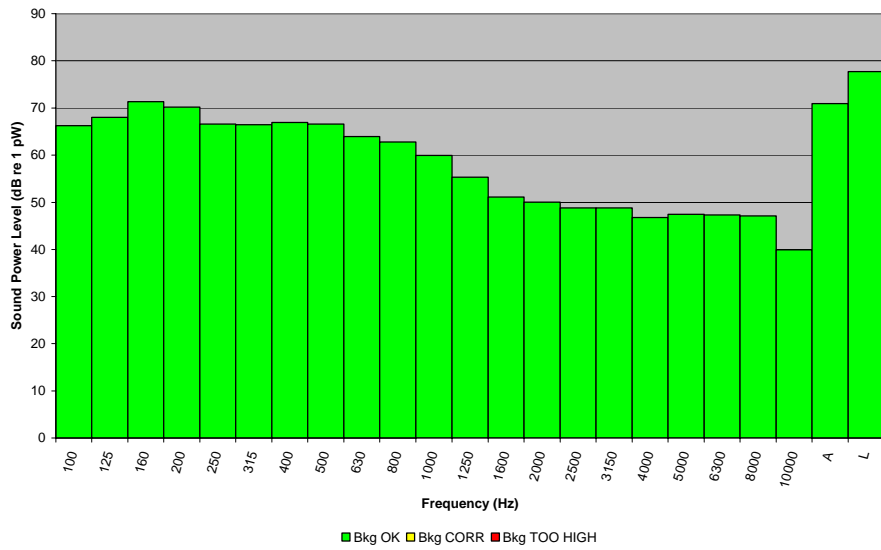
Tapper: Men's Rubber Sole on Oak Floor



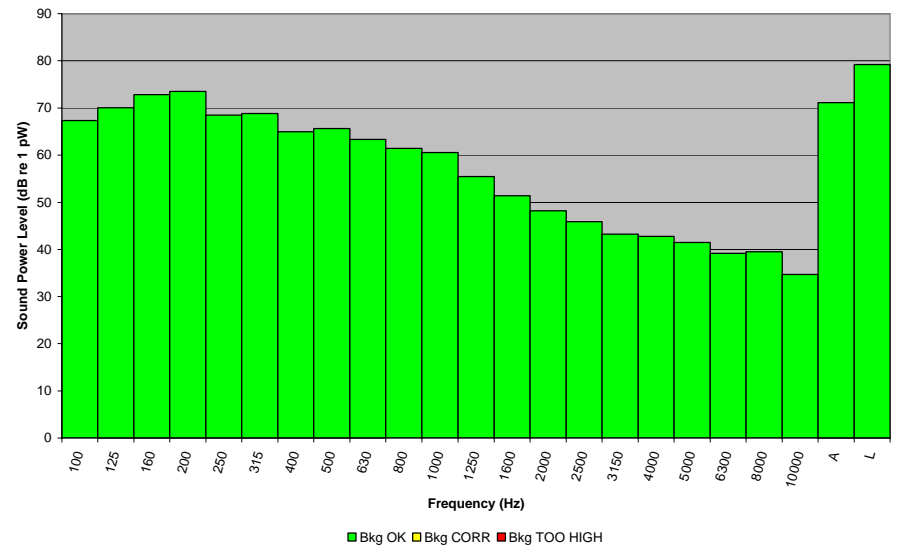
Tapper: Men's Leather Sole on Oak Floor



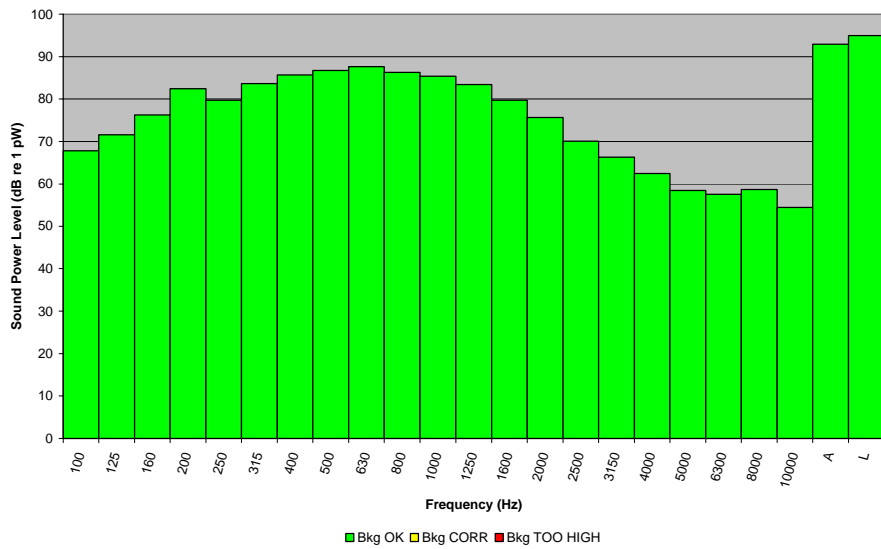
Tapper: Women's Sneaker on Oak Floor



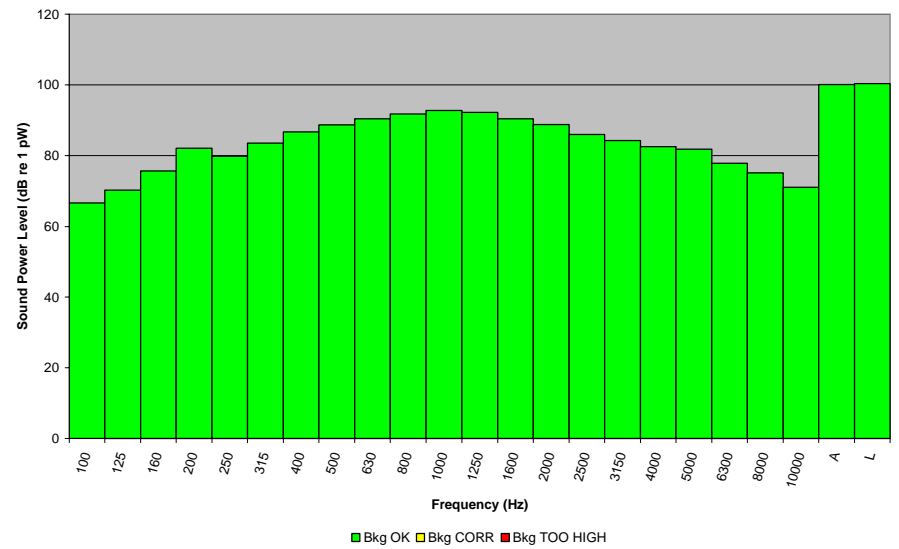
Tapper: Women's Rubber Sole on Oak Floor



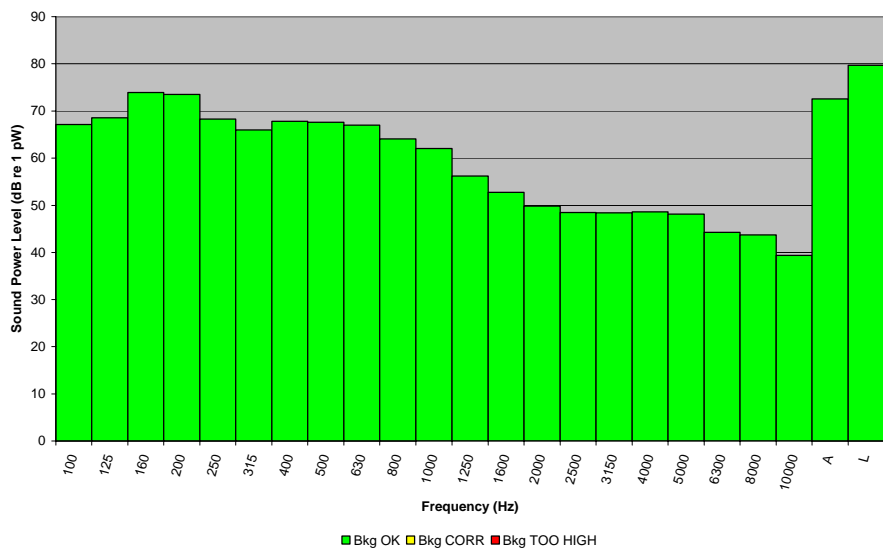
Tapper: Women's Leather Sole on Oak Floor



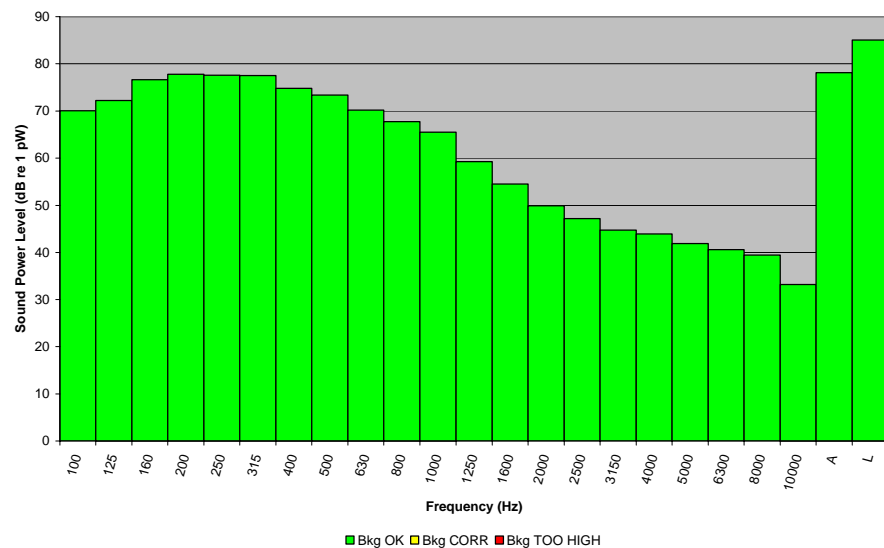
Bare Tapper on Oak Floor



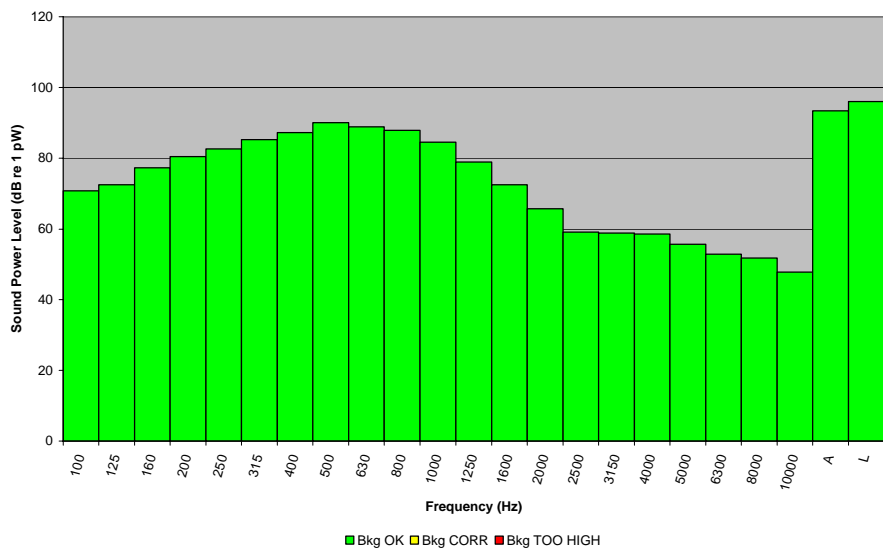
Tapper: Men's Sneaker on Ceramic Tile



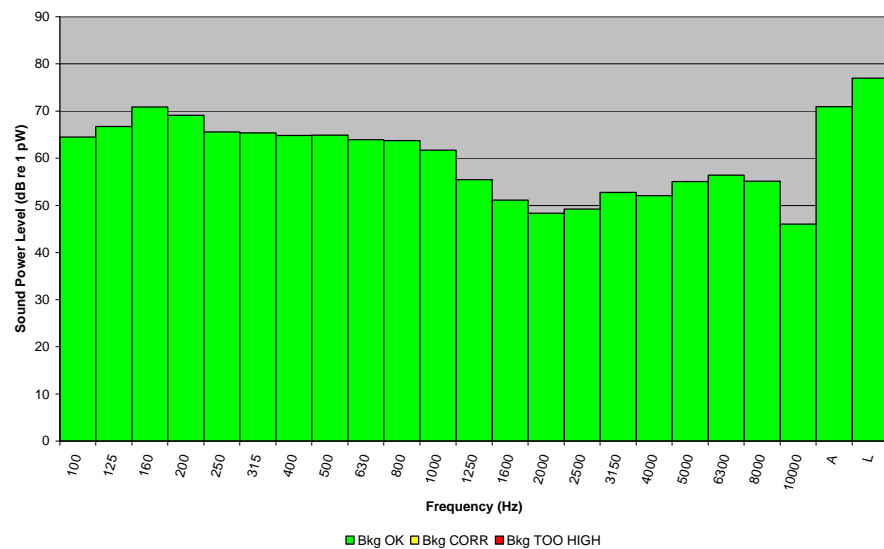
Tapper: Men's Rubber Sole on Ceramic Tile



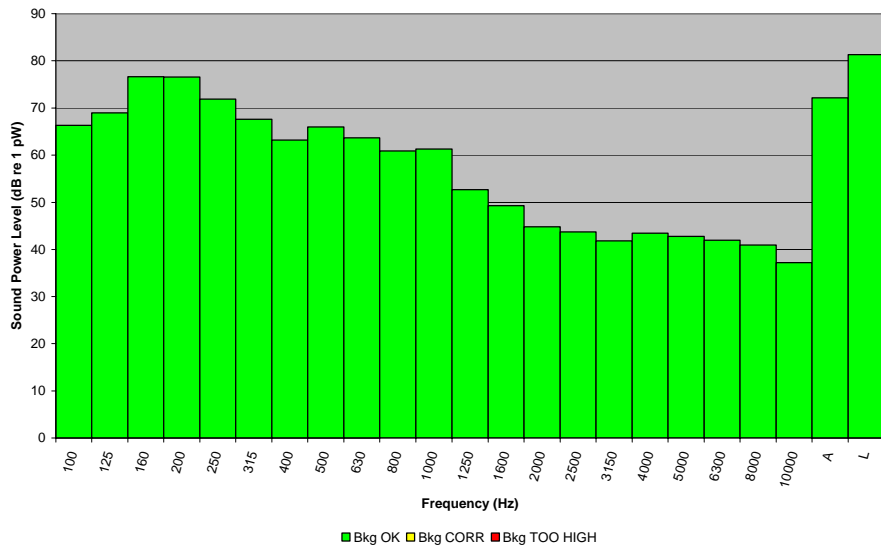
Tapper: Men's Leather Sole on Ceramic Tile



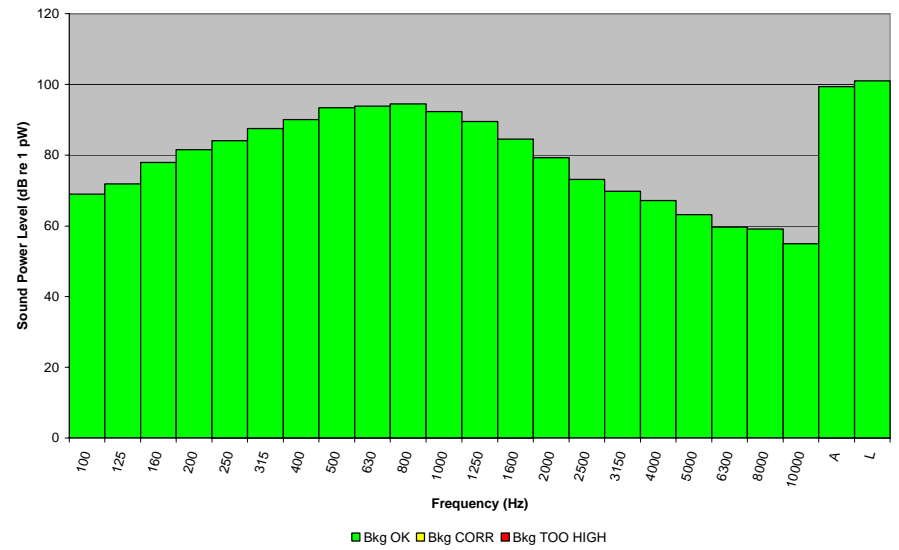
Tapper: Women's Sneaker on Ceramic Tile



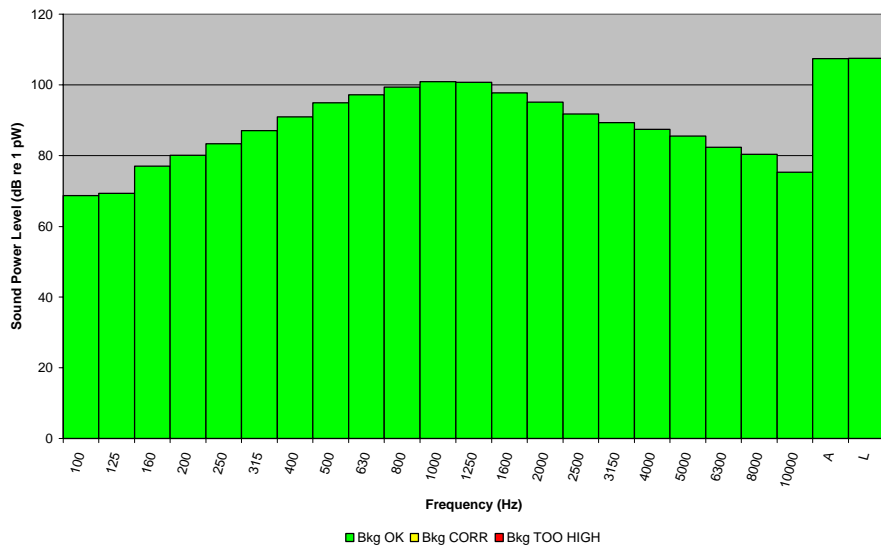
Tapper: Women's Rubber Sole on Ceramic Tile



Tapper: Women's Leather Sole on Ceramic Tile



Bare Tapper on Ceramic Tile



Appendix B: Photographs

Men's Leather Sole

- Mercanti Fiorentini
- Size 13
- Heel: 3 1/8" x 3 1/4"
Nominal 1" thick



Men's Rubber Sole

- Nunn Bush
- Size 13
- Heel: 3 1/4" x 4"
1" thick



Men's Sneaker

- Reebok Classic
- Size 13



Appendix B: cont'd

Women's Leather Sole

- Ditto by Vanelli
- Size 9.5
- Heel: 2" x 2 3/4"
7/8" thick



Women's Rubber Sole

- White Mountain
- Size 8.5
- Heel: 2 1/2" x 2 3/8"
Nominal 1 3/4" thick



Women's Sneaker

- Reebok Classic Princess
- Size 9 Wide

