SENIOR THESIS

Noise exposure associated with marching bands

PREPARED FOR THE MEMBERS of the 2003-2004 DUKE UNIVERSITY MARCHING BAND

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DUMB is loud – we all know that. We joke about hearing loss and going deaf at rehearsals, and no one wants to stand next to the drums because you can't hear yourself think. What if I told you DUMB (and most marching bands) are dangerously loud – enough to cause **permanent hearing loss**? Those headaches and the ringing in your ears that you may get after band rehearsal are warning signs; your body is saying, "Hey! You're hurting me. Please stop."

Stopping this damage may not be as hard as you think. In fact, it is usually just a matter of wearing some simple earplugs. "But earplugs look stupid," you might say. "Besides, I've worn earplugs before, and I can't hear *anything.*" Well, earplugs don't have to look stupid; you can buy clear or skin-toned earplugs for the same price as those ugly orange things. But more importantly, earplugs don't have to block out all noise. Musician's earplugs are specially designed to reduce music to comfortable levels without significantly distorting speech or the music itself. Sound good? It did to me when I first heard about it. Read on to find out more.

Most of you have probably worn foam earplugs at some point in your life; you can get them at drugs stores and pharmacies. Foam earplugs are very good at reducing sound – too good, in fact. They're great for using power tools or mowing the lawn, but foam earplugs reduce high frequency sounds a lot more than they reduce low frequency sounds. High frequency means anything over 2000 Hz (hertz), which includes lots of information found in speech and lots of information found in the upper overtones of musical instruments. The reason that these higher frequencies are lost is due to a property of sound called resonance. Resonating air is what lets us make noise when we blow over the top of a bottle or make different tones by striking glasses full of different amounts of water. In a human ear, there is a resonance at 2700 Hz, and when you stick an earplug into that ear, the resonance is eliminated. This makes everything sound very strange, because we are hearing different amounts of the different frequencies that make up a sound than we normally do.

Scientists and acousticians use a measure called sound pressure level to gauge how loud noises are. SPL is a scientific quantity closely related to what is usually referred to as loudness, and is measured in dB (decibels). Below are some typical SPLs of easily recognized sound sources[1].

SPL (dB)	Typical Sound	SPL (dB)	Typical Sound
120	Jet aircraft takeoff at 60m	60	Normal conversation at 1m
110	Construction site	50	Office / classroom
100	Shout at 1.5m	40	Living room
90	Heavy Truck at 15m	30	Bedroom at night
80	Urban street	20	Broadcast studio
70	Automobile interior	10	Rustling leaves

Here's the problem with foam earplugs[2]:

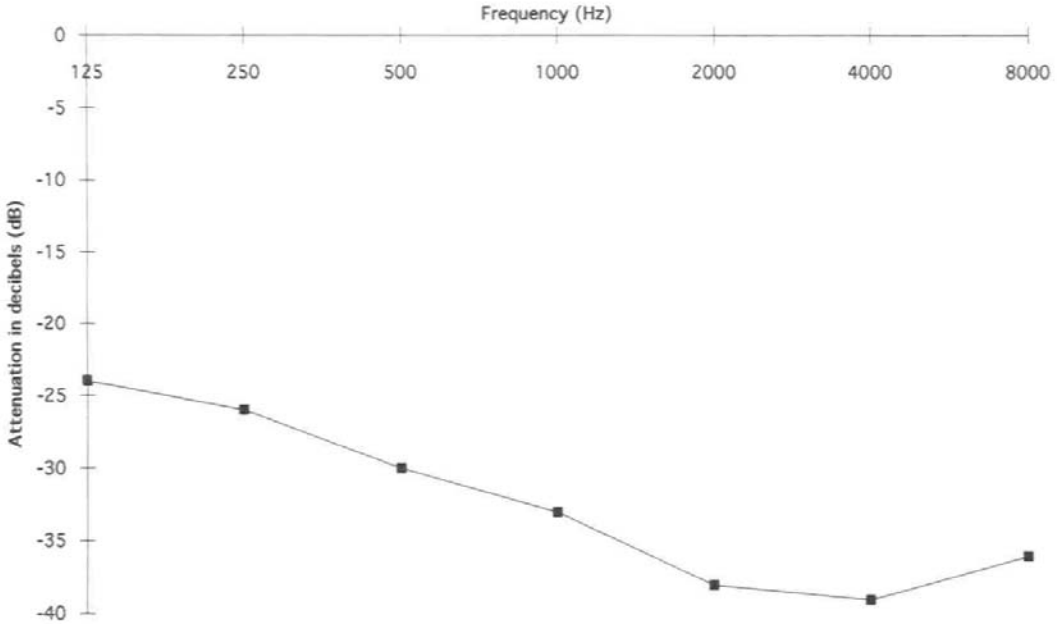

Figure 1: Attenuation characteristics of a typical industrial foam earplug that is deeply inserted into the ear canal.[3]

As you can see, the response is not "flat" at all, which makes everything sound strange.

So, are foam earplugs better than nothing? Yes and no. Obviously, if you are being exposed to dangerous levels (and you will see below that you are), you need to do *something* about it. I used foam earplugs for three years when I was in high school. I'm sure they protected my hearing, but I was constantly pulling them out so I could understand what people were saying and putting them back in to play. This is a pretty big pain, plus it gets the earplugs dirty and wastes time. Also, it's definitely not a good idea to have an entire band wear foam earplugs. Generally wind players wearing foam earplugs tend to overblow to replace lost harmonics and percussionists tend to overstrike to replace stick strike and head slap noises.

So, what to wear instead? The answer is musician's earplugs. The key to musician's earplugs is flat response. These earplugs eliminate the effects of closing off your ear canal, so that the spectrum of the sound is reduced overall, but the shape doesn't change. Etymotic Research, Inc. has produced two flat-response earplugs, the ER-15 and the ER-25, respectively providing 15 and 25 dB of sound attenuation regardless of frequency.

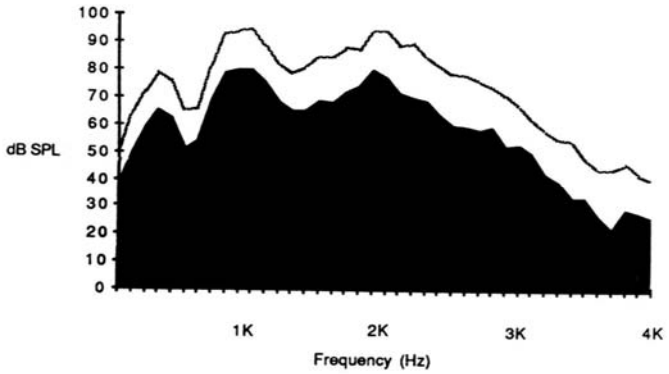

Figure 2: The effect of the ER-15 earplug on a violin playing at 440 Hz. The white spectrum in the un-attenuated sound level and the black spectrum is the attenuated sound level.[4]

Pretty cool, huh? I thought so too, so I got a pair of ER-25s. The first time I wore them to a football game I was amazed. The crushing headaches I was getting at games must've had something to do with being assaulted by noise and not just the spectacular dive, dive, dive, punt football offense. The muffled feeling I would sometimes get in my ears disappeared as well. If you ever get the chance, watch people after they come out of a loud band rehearsal; chances are they'll be yawning. It's not because they're tired, it's because they can't hear as well and their brains think their ears need to pop. It doesn't work, of course; only time and rest can heal temporary hearing loss. Once the loss becomes permanent, nothing can reverse it.

Figure 3: A pair of ER-15 / -25 earplugs.[5]

So now I avoid all of this yawning nonsense by wearing my ER-25s whenever things get loud; you've probably seen me with them in Cameron or Bone. Ray Eddy has pair, too, and he wears them whenever he's with a band that's playing indoors. Unfortunately, ER-15s ands -25

are rather expensive (between $125 and $200, including production and initial fitting of the necessary earmolds). Personally, I feel it is well worth the one-time cost for any musician who plans to participate in ensembles for a long time. After all, they are no more expensive than a set of long-use contacts or a pair of glasses, and I feel they have the same medical benefit. However, you may not feel the same way. If that is the case, keep reading. Your parents, if they generally pay for this sort of thing, also might not feel the same way. If *that's* the case, feel free to have them come read this, and then see what they have to say. I think the argument for protection is pretty convincing.

If you do decide to get ER-15s or ER-25s, the procedure is very simple. You must visit an audiologist, who will squirt some goo into your ear that hardens into a mold. This mold gets sent out for production, and in about two weeks you get a set of custom-fit earplugs with the ER-15 or 25 inserts. You can even order both sets of inserts and switch them back and forth in the same mold for different levels of protection. If you haven't had an audiogram in a while (that test where you push the button every time you hear a tone), or if you don't have one on record at all, you should also have that done. This will give the audiologist a reference level on your hearing, and later you can come back and see if it's changed.

So how do these ER earplugs actually work? Some of you may be content to accept the fact that they just do. For the rest of you, here's a short explanation. If you're familiar with basic physics and RLC circuits, this should make sense; if not, don't worry about it.

A schematic of the ER-15 is shown below. The ER-15 and -25 earplugs use a small button containing a thin plastic diaphragm and an acoustic resistance (R1 in the schematic). The compliance (C1) of the diaphragm is selected to produce the desired 15 dB of attenuation at low frequencies. At high frequencies, because the normal open ear produces a *boost* of about 15 dB at 2700 Hz, 15 dB of protection at 2700 Hz requires 0 dB of attenuation through the earplug at that frequency. In order to produce that 0 dB of attenuation, the dimensions of the sound channel in the earmold are adjusted so that the acoustic mass (L1) of the air in that channel resonates with the diaphragm compliance and forms a peak at 2700 Hz. Finally, an additional tuned resistive element (R2) is added to smooth the peak. For an ER-25 earplug, the compliance is reduced to increase attenuation and the diaphragm and resistors are adjusted to maintain the shape of the response.[6]

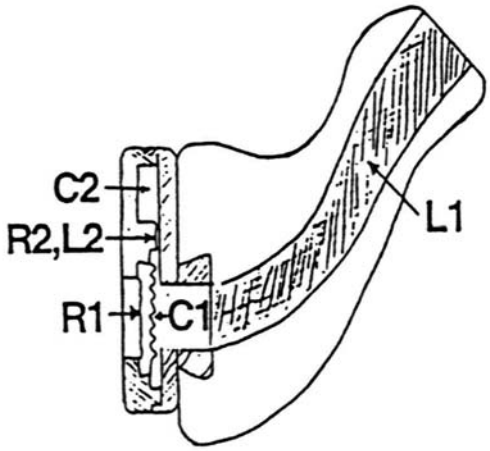

Figure 4: The ER-15 earplug; C stands for compliance, R for resistance, and L for inductance.[7]

But what if you can't afford ER-15 or -25 earplugs? The ER-20 is the answer; it is neither as flat in response nor nearly as expensive as the ER-15 or -25. This is not a custom plug; it is one size fits most, and retails for less than $15. ER-20s are available via the internet and in an increasing number of retail stores serving musicians. The ER-20 consists of a triple flange design that when fully inserted into the ear provides a semi-flat response with 20dB of attenuation.

Figure 5: A pair of ER-20 earplugs.[8]

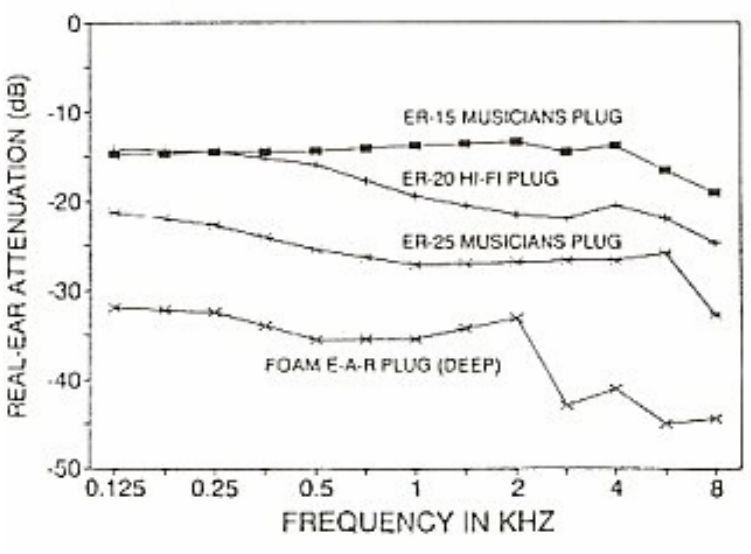

Figure 6: Attenuations of ER-15, ER-20, ER-25, and foam earplugs.[9]

Hopefully now you understand how musician's earplugs work. **I highly recommend that Neil or the athletic department purchase ER-20s for the entire membership of DUMB and encourage their use.** You will see below that some of the exposures during Duke rehearsals and performances are truly frightening.

As you probably know, I used a sound level meter to record the decibel levels during the 2003 marching band season rehearsals and performances. Measurements were also taken with the Riverside High School Marching Band (Riverside High School is about three miles from East Campus). While attempting to remain as out of the way as possible, I tried to get the microphone as close as possible to band members' heads. Since I've been in marching band for nine years, I used my experience to help me take measurements as realistically as possible.

So, how loud is too loud? There is plenty of debate over that question; I have chosen to use recommendations from the National Institute of Occupational Safety and Health. While these numbers are designed to be used for noise exposure in the workplace, they do a reasonable job of letting us know when exposures from a band are dangerous.

To adjust the response of a sound level meter, frequency-weighting scales are used. The most often used weighting scale (and the scale used in almost all noise standards) is the A scale, expressed as dBA or dB(A); it approximates the response of the human ear to moderate level sounds and includes a large low-frequency drop-off. The C scale approximates the response to high level sounds, and incorporates small drop-offs at both low and high frequencies. Despite the fact that this study deals with high level sounds, A weighting is used throughout for comparison with noise exposure standards. Below are the combinations of exposure and duration that are considered safe.

Exposure (dBA)	Duration			Exposure (dBA)	Duration		
	Hours	Minutes	Seconds		Hours	Minutes	Seconds
80	25	24	--	106	--	3	45
81	20	10	--	107	--	2	59
82	16	--	--	108	--	2	22
83	12	42	--	109	--	1	53
84	10	5	--	110	--	1	29
85	8	--	--	111	--	1	11
86	6	21	--	112	--	--	56
87	5	2	--	113	--	--	45
88	4	--	--	114	--	--	35
89	3	10	--	115	--	--	28
90	2	31	--	116	--	--	22
91	2	--	--	117	--	--	18
92	1	35	--	118	--	--	14
93	1	16	--	119	--	--	11
94	1	--	--	120	--	--	9
95	--	47	37	121	--	--	7
96	--	37	48	122	--	--	6
97	--	30	--	123	--	--	4
98	--	23	49	124	--	--	3
99	--	18	59	125	--	--	3
100	--	15	--	126	--	--	2
101	--	11	54	127	--	--	1
102	--	9	27	128	--	--	1
103	--	7	30	129	--	--	1
104	--	5	57	130-140	--	--	<1
105	--	4	43	--	--	--	--

Data are presented according to whether they present no risk for the duration of the measurement or the estimated exposure time (green), risk for the estimated exposure time but not the duration of the measurement (orange), or risk for both the duration of the measurement and the estimated exposure time (red).

INDOOR REHEARSAL - DUKE UNIVERSITY, WITH DRUMLINE				
SPL (dBA)	Location	Principal Sources of Exposure from other instruments	Sample Time	Exposure Time
98.3	drum major (warmups and tuning)	entire band	0:12:21	0:12:21
98.8	between clarinets and alto saxophones	brass	0:11:45	(1:15:00)
99.4	tenor saxophones	marching percussion	0:07:32	(1:15:00)
99.6	flutes	mellophones, trumpets	0:09:32	(1:15:00)
100.2	drum major	entire band	**1:26:20**	**1:26:20**
103.6	alto saxophones	trumpets	0:11:13	(1:15:00)
104.1	between snare drums and bass drums	marching percussion	0:09:46	(1:15:00)
105.3	snare drums	marching percussion	**1:01:44**	**1:01:44**
106.0	cymbals	marching percussion	0:07:53	(1:15:00)
107.8	trumpets	marching percussion	0:09:19	(1:15:00)

INDOOR REHEARSAL - RIVERSIDE HIGH SCHOOL, W/O DRUMLINE				
SPL (dBA)	**Location**	**Principal Sources of Exposure from other instruments**	**Sample Time**	**Exposure Time**
89.5	pit	none	0:04:43	(1:00:00)
90.9	trumpets	trombones, CT	0:10:22	(1:00:00)
93.9	flutes (warmups and tuning)	trumpets	0:05:50	(0:10:00)
94.9	drum major	entire band, CT	0:06:31	(1:00:00)
95.0	flutes	alto saxophones, mellophones, CT	0:08:06	(1:00:00)
95.7	pit	CT	0:07:55	(1:00:00)

INDOOR REHEARSAL - RIVERSIDE HIGH SCHOOL, WITH DRUMLINE				
SPL (dBA)	**Location**	**Principal Sources of Exposure from other instruments**	**Sample Time**	**Exposure Time**
96.4	bass drums	marching percussion	0:03:42	(0:30:00)
96.5	tenors	marching percussion	0:01:26	(0:30:00)
100.2	flugelhorn	bass drums	0:01:01	(0:30:00)
100.5	sousaphones	marching percussion	0:01:31	(0:30:00)
101.5	between snare drums and bass drums	marching percussion	0:04:10	(0:30:00)

INDOOR REHEARSAL - DUKE UNIVERSITY DRUMLINE			
SPL (dBA)	**Location**	**Sample Time**	**Exposure Time**
99.8	observer/instructor position (center of arc)	0:29:35	(1:30:00)

OUTDOOR REHEARSAL - RIVERSIDE HIGH SCHOOL DRUMLINE			
SPL (dBA)	**Location**	**Sample Time**	**Exposure Time**
96.0	snare drums	0:02:55	(0:35:00)
98.9	between snare drums and bass drums	0:14:46	(0:35:00)
103.0	bass drums	0:03:54	(0:35:00)
104.7	tenors	0:06:55	(0:35:00)

OUTDOOR REHEARSAL - RIVERSIDE HIGH SCHOOL				
SPL (dBA)	**Location**	**Principal Sources of Exposure from other instruments**	**Sample Time**	**Exposure Time**
84.8	clarinets (backfield)	none	0:00:14	(2:00:00)
86.1	drum major (show run-through)	entire band, CT	0:06:35	(2:00:00)
86.1	trumpet	entire band, CT	0:01:53	(2:00:00)
86.6	pit	trumpets, CT	0:03:13	(2:00:00)
87.2	trombone	baritone, sousaphones	0:00:17	(2:00:00)
88.6	alto saxophone (show run-through)	low brass, CT	0:01:56	(2:00:00)
88.8	clarinets / alto saxophones	mellophones, trombones	0:00:25	(2:00:00)
89.3	piccolo	marching percussion, CT	0:04:50	(2:00:00)
92.3	baritone (show run-through)	low brass, CT	0:01:17	(2:00:00)
94.1	piccolo	marching percussion, CT	0:01:03	(2:00:00)
94.4	flugelhorn (show run-through)	low brass, alto saxophones	0:02:03	(2:00:00)
94.5	mellophones	low brass, CT	0:00:10	(2:00:00)
94.7	snare drums	marching percussion, CT	0:04:19	(2:00:00)
94.8	bass drums	marching percussion, CT	0:00:57	(2:00:00)
95.3	pit (percussion solo)	marching percussion	0:00:15	(2:00:00)
95.9	sousaphone	sousaphone, trombones, CT	0:00:19	(2:00:00)
98.6	tenors (show run-through)	marching percussion, trumpets	0:06:02	(2:00:00)
100.1	pit	brass	0:00:15	(2:00:00)
105.8	snare drum (show run-through)	marching percussion, brass	0:01:35	(2:00:00)

OUTDOOR STANDS MUSIC - DUKE UNIVERSITY				
SPL (dBA)	**Location**	**Principal Sources of Exposure from other instruments**	**Sample Time**	**Exposure Time**
98.6	tenor saxophones	trumpets	0:20:42	(2:30:00)
101.2	mellophones	trumpets	0:24:58	(2:30:00)
103.4	bass drums	marching percussion	0:27:56	(2:30:00)
103.5	drum majors	marching percussion	0:22:46	(2:30:00)

DUKE UNIVERSITY, CAMERON INDOOR STADIUM[+]				
SPL (dBA)	**Location**	**Principal Sources of Exposure from other instruments**	**Sample Time**	**Exposure Time**
96.9	drum major (women's game)	entire band	1:24:04	(4:00:00)
99.5	trombones	clarinets, flutes	0:18:45	(4:00:00)
100.6	sousaphone	sousaphones, trumpets	0:26:45	(4:00:00)
101.1	between bells and drumset	bass drum, cymbals	0:49:36	(4:00:00)
101.2	drum major	entire band	2:23:44	(4:00:00)
101.3	between flutes and clarinets	alto saxophones, trumpets, mellophones	1:06:29	(4:00:00)
102.5	alto saxophones	trumpets	1:25:04	(4:00:00)
102.8	drum major (vs. CAROLINA)	entire band	**3:46:08**	(4:00:00)

[+]all measurements taken at men's games unless otherwise noted

As you can see, earplugs are necessary in the majority of situations to stay safe. The safest locations are inside without the drumline and outside in the woodwind section; however, DUMB rarely rehearses inside without the drums. The most dangerous locations are both inside and outside near drums or brass. Wally Wade, despite the lack of any strong reflecting surface to the front of the band and any surface at all above the band, is *very* loud for an outdoor location. The numbers are even worse when you consider that the estimated exposure times do not include our two field shows per game, nor do they include the exposure during the pregame rehearsal, the march to the stadium, or the playing on the concourse. Cameron is even worse; if you stay for a whole game, you are well over the recommended safe times for even the quietest game measured.

The numbers show that marching band can be dangerously loud all alone, but many of you are in plenty of other ensembles. The noise exposure you may get in wind symphony, jazz ensemble, orchestra, pit orchestra, and vocal groups may also be damaging, or it may take away the much-needed rest your ears need after marching band.

Using ER-25 earplugs, every decibel level listed would be reduced to levels below 85 dB. ER-20s or -15s would reduce exposure to safe levels for the durations of exposures.

♪ ACKNOWLEDGEMENTS ♪

Dewey Lawson

Riverside High School Marching Band Members

Ken Davis, Riverside Band Director

Duke University Marching Band Members

Neil Boumpani, Duke Marching Band Director

ENDNOTES

[1] Rossing, Thomas D. The Science of Sound. Reading: Addison-Wesley Publishing Company, Inc., 1990. p. 86.

[2] Chasin, Marshall. Musicians and the Prevention of Hearing Loss. San Diego: Singular Publishing Group, Inc., 1996. p. 86.

[3] Chasin, p. 86.

[4] Chasin, p. 88.

[5] "Earplugs – ER9 – ER15 – ER25." Online. 14 April 2004. <http://www.ultimateears.com/earplugs.htm>.

[6]Beck, Douglas L. Interview with Mead Killion, Ph.D., Founder of Etymotic. 18 August 2003. Online. 16 April 2004. <http://www.audiologyonline.com/interview/displayarchives.asp?ID=215>.

[7] Chasin, p. 89.

[8] "Cabot ER20 EAR HiFi Ear Plugs." zZounds.com. Online. 12 April 2004. <http://www.zzounds.com/item--CABER20>.

[9] "High Fidelity Earplugs." Otarion Hearing Aid Centre. Online. 14 April 2004. <http://www.auracom.com/otarion/earplugs.html>.