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Impulse noise from weights dropped on concrete floors.

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Impulse noise and vibrations in buildings are common from weight drops in gyms. There are a growing emphasis and literature on the matter, often supported by the floor or mat-industry. We will show measurements of impacts from free weights, and Olympic bar with bumper plates and insertion loss for mats and different designs of floating floors. Reference noise levels from weight drops of typical sources are given. Realistic potential energies and impact forces are discussed. The differences between impact sources like bumper plates, grip plates, hand manuals and kettlebells, as well as the physics and nature of some of the typical lifts are discussed, leading to suggestions for possible drop energies and noise levels from weight drops in gyms.

1 Introduction

Strength training has become trendy. Gyms are often in the same building as offices, shops, or apartments, some with no or limited manning and opening hours 24/7 or early hours: 06:00-22:00 in average. Noise conflicts sometimes appear between the user groups, the apartment cases being the difficult. About 22% of the open gyms in Oslo (ca 175) lie in the same building as apartments, some 35% with offices and 46% with shops, workshops, groceries and similar. Some share building with two or more categories and a few gyms lies alone.

We will focus on the structural noise from impacts generated by dropped weights. First, we will introduce some typical impact noise sources and their upholstering. Then we will assess the drop energies that can appear in a gym based on the typical activities. Furthermore, we will discuss the insertion loss (IL) the mat and floor solutions typically must deliver, to meet noise limitations in workshops, shops, offices, and apartments.

2 Types of impact sources and exercises

Weight training noise sources in gyms vary from basic Olympic lifting bars with bumper- or grip plates to plastic or rubber covered hand manuals (dumbbells), barbells with grip plates or a similar construction to dumbbells, and bare cast iron “Kettlebells”. Most gyms will have cable machines for arms, upper body, back, core and lower body (legs) training. Cable machines usually have weight magazines of a set of flat 2,5 kg plates with a mechanism for variable load, see Figure 2. Other impulsive sources are medicine balls (2-9 kg), battle ropes ca 6 kg, and machines with manually added weight plates. Body weight and explosive training like jumping on boxes of different height and mill running are other examples.

Figure 1: Combination of soft rubber granulate bumper plates and grip plates giving a narrow and softer contact area with 30 mm deflection room. Adding and removing weights are easy. Right: chromed pure metal dumbbells with typical heaviest @ 10 kg.

Grip plates usually have a 5-10 mm rubber or urethane layer on them. Bumper plates for Olympic dumbbells are usually made of massive rubber, rubber-granulate or urethane covered rubber with depth up to 160-200 mm. Some of them may contain some steel.

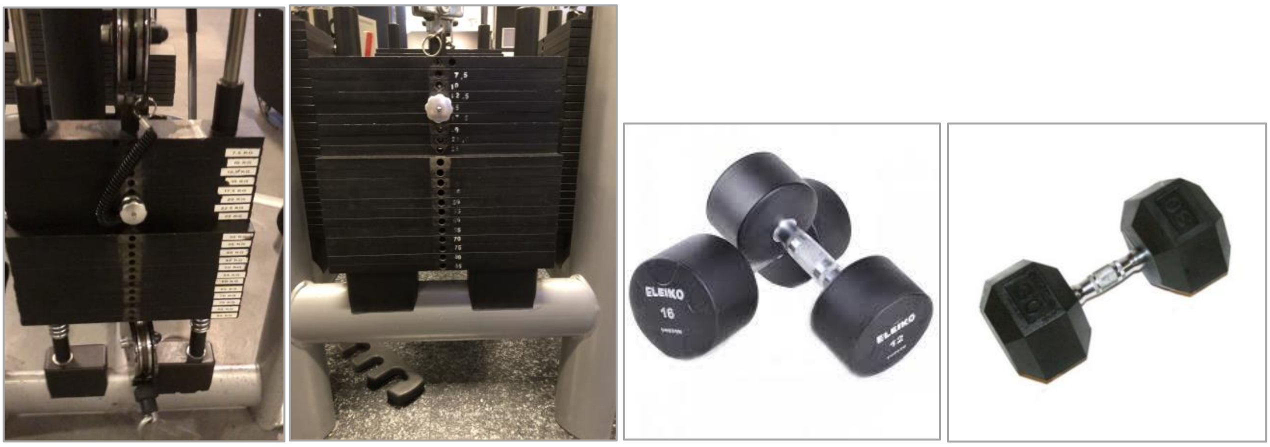

Figure 2: 80 kg and 85 kg weight magazines for cable machines with spring and rubber block supports. Right: Urethane or rubber covered dumbbells 1 - 40 kg.

Dumbbells are covered with rubber or urethane. Our 40 kg Eleiko manual has 12 mm of urethane over the steel and our hexagonal 42,5 kg has 20mm of rubber, both some 80 and 90 Shore A hardness for durability. Bumper plates may be equally hard, the Eleiko XF rubber granulate ones are 70-75 Shore A depending on age. Older rubber is harder.

2.1 Exercises and drop energies, mgh.

The heaviest lifts are those training the largest muscle groups legs, butt and core muscles, like squats, deadlifts, leg press, hip thrust, bench press, leg extension and - curls. For press or pulling lifts like the basic lifts, *squat*, *deadlift* and *bench press*, the only limit is the strength. For machines, the body weight will usually be a limiting factor, unless the apparatus does simulate basic lifts in some way. The drop energy is proportional to the mass, m, the drop height, h, and the gravitation acceleration, $g = 9{,}82$ kg*m/s^2. The lifts with the largest mass dropped from the highest height have the potential to generate most impact force, noise and vibrations.

2.2 Lifts with potentially highest drop energies.

The highest lifts are Olympic, dropping the weights from overhead. Doing these lifts safely takes a long time of training. Not many are able to lift more than 100 kg overhead. Olympic lifts are regular in *crossfit*. Other overhead lifts are *shoulder press*, *front press*, *overhead press*, but these are usually handled from a rack or sitting on a bench.

Squats with the bar on the shoulders is also handled from racks with or without safety bars below. Failure lifts may lead to heavy drops from shoulder height, usually on the way up. Such failure drops are very rare in regular gyms. The strongest lifters in the gyms are usually the personal trainers, the PT's. A strong PT or lifter may lift above 200 kg in a squat. An average male gym user may lift 100-110 kg. With 1,5m shoulder height these weights have a potential drop energy of 2,9 kJ and 1,5 kJ, respectively.

Dropping the deadlift weights from upright position is unusual. But such a drop may be a reliable source for tests like 80-120 kg dropped from 0,53 m giving 420-625 J of energy.

2.3 Dumbbells and grip plates, good sources.

Dumbbells are probably the most dropped weights in a gym, followed by grip plate handling and deadlifts. Dumbbells turn out to be quite stable sources, rolling them from a bench. The spectrum from a rubber or urethane covered dumbbell on concrete is quite like the spectrum from a grip plate drop on the end of the plate, given that they are covered with some rubber or urethane plastic. Dumbbells can be heavier than most grip plates. The heaviest dumbbell is 40-42,5kg, sometimes 50 kg. A drop from a bench gives about 165-206 J energy. If dropped from sitting shoulder height, 1,1m, the drop energy will be 540 J.

2.4 Source levels from literature and own measurements.

Figure 3 show some literature data as well as own measurements of drop impulse noise levels. The harder dumbbells, grip plates and the kettlebell dropped on 8 mm rubber give about 14 dB louder impulses than the rubber bumper plates.

Dropping a 40-42 kg dumbbell from a bench about 0,42 m give impulse maxima from $L_{A,\,max}$ = 92-101 dB, a method documented in Hayne [1]. $L_{A,\,max}$ = 96-97 dB may be a relevant level to use, measured at 2,5-3m distance in the same room, under the impacted slab or in a neighbor room.

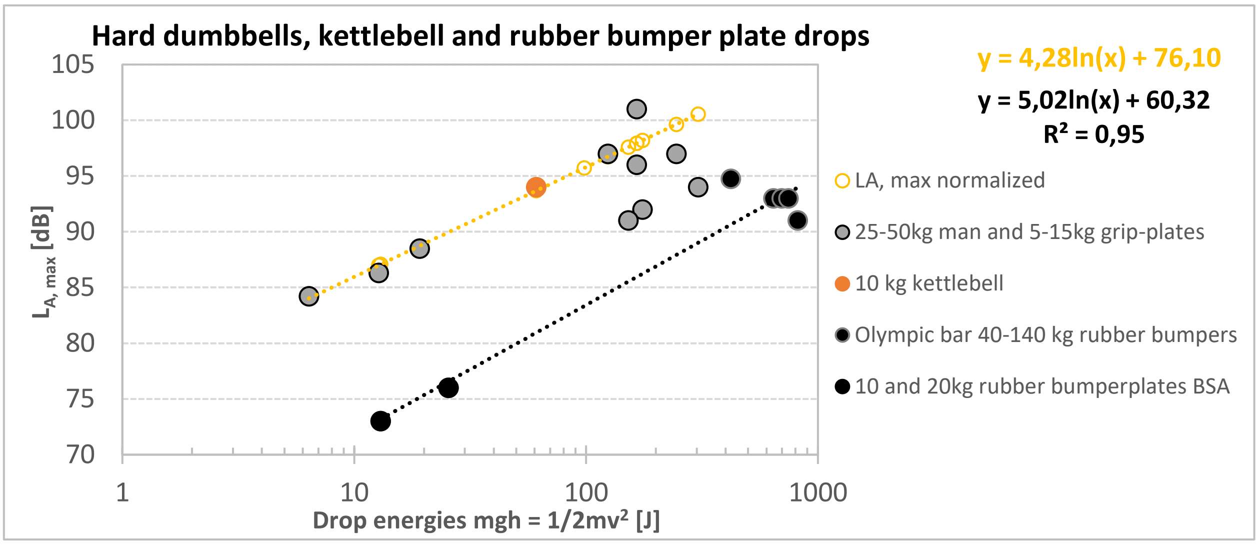

Figure 3: Drop noise levels for hard dumbbells (manuals) and grip plates: grey dots. A kettlebell on 8 mm rubber: orange dot. Two rubber bumper plates: black dots. Olympic bar with rubber bumper plates 40-140 kg: black dots with grey rings. Data from Hayne [1], Crosstick [2], Murray [3] and our own measurements. Olympic bar with bumper plate drops generates some airborne rattle noise when dropped on hard surfaces, see Figure 4.

2.5 Impact noise spectra from Olympic bar with bumper plates.

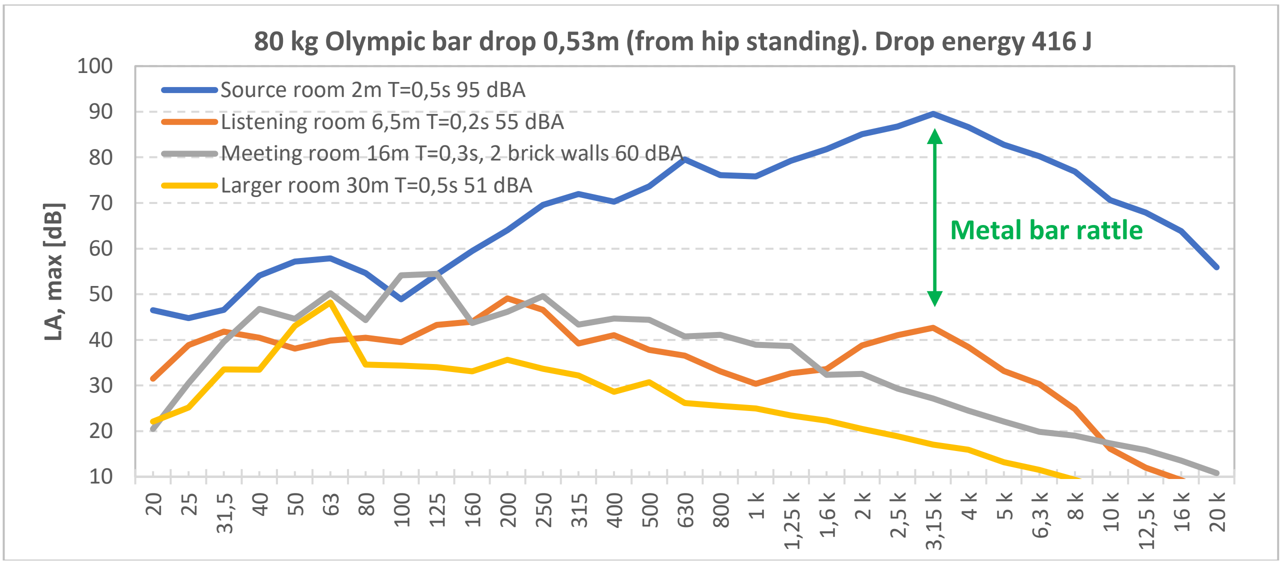

Figure 4: $L_{A,\,max}$ spectra from 80 kg Olympic bar dropped from hip height on vinyl floor measured in the source room (blue), and rooms in 6,5 m distance (orange), 16 m (grey) and 30 m distance from the source (yellow).

At larger distances we see a slowly falling spectrum from about 63-125 Hz. We also see room modes and/or structural modes at 50-63 Hz in the large room, and 100-125 Hz in the meeting room.

If we compare the information from the measured Olympic bar drop spectra and the damping we can get from a mat, given in Figure 5, the possible effective damping of the Olympic bar drop noise will be limited. Drop tests gave ca 6 dB for the 50 mm mat and 10 dB for the 70 mm mat.

2.6 Impact noise spectra from dumbbell drops on vinyl and mats.

A-weighted impact spectra from a dumbbell drop on vinyl and mats, Figure 5, show how gradually thicker mats influence the noise spectra from a 40 kg hand manual dropped from 42 cm, 165 J. The 14 mm mat has effect from 200 Hz, the 50 mm mat from 80 Hz and the 70 mm mat from 63 Hz.

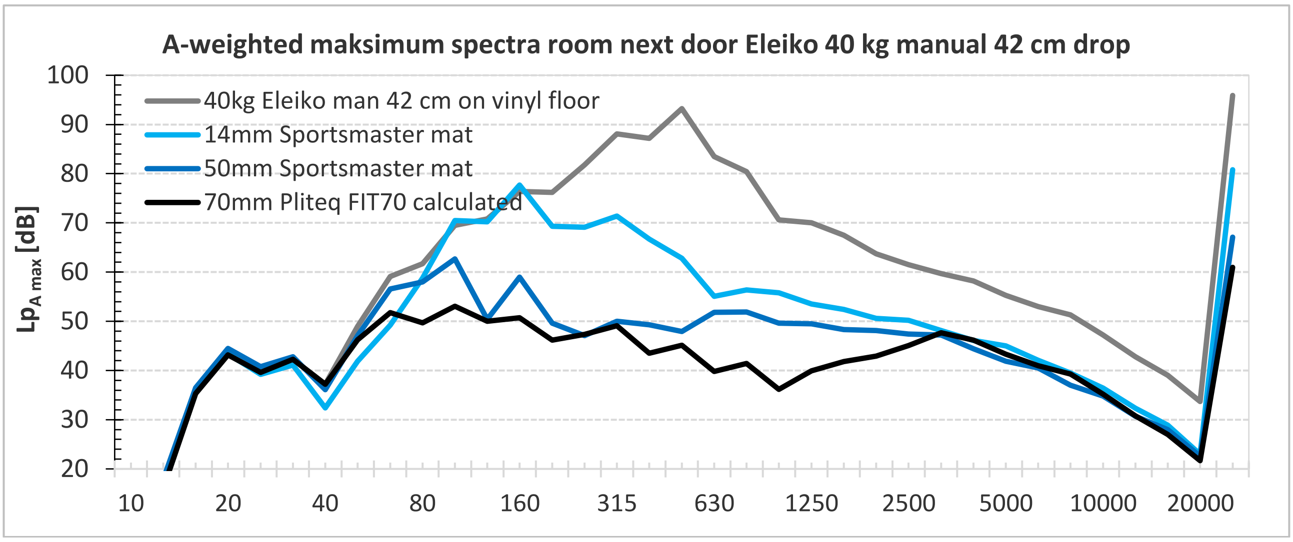

Figure 5: Drop tests with 40 kg manual dropped 42 cm on a vinyl floor (grey), 14 mm and 50 mm rubber + rebound PUR mix mats (light and dark blue) as well as a 70 mm rubber granulate mat (black). The 50 mm and 70 mm mats have a shaped underside with about 20 % contact area.

The IL can be read from the difference between the rightmost data. The IL increases with the thickness: 15 dBA, 29 dBA and 29 dBA, respectively.

The hard floor dumbbell drop has its main energy in 315 Hz-800 Hz indicating a short impact. The Olympic bar drop show a falling spectrum from about 63-125 Hz when we disregard the produced rattling noise. The bumper plates and Olympic barbell give a longer impact than the rigid and hard hand manual.

3 What drop energies and forces can we expect?

How strong does the impacts regularly tend to be? In the gym I frequent my PT think that his 50 kg manual drop from shoulder height 1,1 m on a 30 mm mat is the strongest regular impact in the gym. That is an impact energy of about 2 x 540 J. On a 30 mm mat that should give about 2*65 kN force, 20log(F) = 96 dB re 1 N and the expected $L_{A,\ max}$ = 81 dBA or 85 dBA if the impacts from both appear in the same 125 ms window. The gym regularly receives complaints from the store below from these impacts, as well as from heavy deadlift drops.

Impact energies up to about 600 J must be expected quite regularly in a gym. In case of failures, way higher energies may occur. Up to 3,7 kJ is possible for a shoulder height failure-drop from a strong squatter. This happens very seldom.

Olympic lifts can generate drop energies of about 2-3 kJ, depending on the abilities of the lifter. Drop forces can become up to 500-800 kN with hard bumper plates with no or thin mats. (The calculation of force from dropped weights are based on Hertzian contact from Tempelmann [4], originally from Hunter [5]: $F_{max} = (2{,}98)^{1/2}mgh/y_{max}$). With 50 mm mats the drop forces may come under 100 kN for such drops, but they will still be noisy.

3.1 Measured and calculated IL for dumbbell drop tests on mats and on floating floors.

The mitigation against impulses from gyms is mats, light, or heavy floating floors of different designs as well as damping solutions on the machines and equipment. Insertion losses (IL) is here defined as the $L_{A,\ max}$ level measured, in the same position, with one or several mics in a room or one accelerometer, or several, on the floor slab, with and without a mat or floor solution under a dropped object with the same drop energy both times.

The IL for a floating floor is expected to increase with lower resonance frequency of the system with an increasing trend from about 1,4 times the resonance frequency, f_0.

Heavy floating floors may have an improvement from 6 dB per octave for continuous floating layers with high damping to 9 dB per octave for point supported floors with low damping. The theoretical improvement for light floating floors is 18 dB per octave.

All such floors will have negative IL's around the resonance frequencies ± $1,4f_0$. It is important to push these resonances as low as possible to improve the performance and benefit from the reduced hearing sensitivity in the low frequencies.

3.2 Floating floor resonance, performance, and the effect of the enclosed air

There are limitations, however, as to how soft a floating floor can become, given that the airspace under it is closed. The air spring will work in parallel with springs, elastomer line- or point supports, or just the dynamic skeleton stiffness of the continuous elastic porous layer.

Mineral, glass wool or any other porous material like rebound PUR foam or similar will reduce the air stiffness due to isothermal compression. The sound speed in a porous layer can be a tenth of what it is in free air, leading to a lower impedance and thus reduced stiffness. The air stiffness without porous material is *146/d* [MN/m^3] where the *d* is the airspace in mm. In a porous medium, like mineralwool, it will be some *115/d* [MN/m^3]

For a floating floor with a porous material under it the resonance frequency f_o will be:

$$f_0 = \frac{1}{2\pi}\sqrt{\left(\frac{115}{d} + s\right) 10^6 \left(\frac{1}{m_{fl}} + \frac{1}{M_s}\right)} \tag{1}$$

Where m_{fl} is the mass [kg/m^2] of the floating floor and the M_s is the mass [kg/m^2] of the floor slab below. *S* is the dynamic skeleton stiffness [MN/m^3] of the porous material, stripe, point supports or springs.

A floating concrete floor with thickness 115 mm floating on a 200 mm concrete floor slab with 100 mm of a porous material with dynamic skeleton stiffness of about 5 MN/m^2 will give a floating floor resonance f_0 = 29 Hz.

For a spring supported floating floor we remove the porous material and have a 40 mm empty airspace with a system of springs with a 5 Hz resonance frequency for the concrete mass and springs, disregarding the air stiffness. We choose not to vent the airspace: We will then get an f_0 = 23 Hz, and we have a floor that does not perform much better than the floor example above with 100 mm mineral wool.

However, if the airspace is successfully vented, and the air stiffness can be neglected, the performance becomes much better (in theory), giving the spring supported floor resonance at 5 Hz. The IL from measurements from one such floor type is shown in Figure 6 both without a mat and with a 50 mm mat. It is the best data in the set. The raw IL data comes from the provider.

3.3 Mat and floating floor insertion loss data

Mat data from the literature and some own measurements from a 40 kg manual drop from bench height is shown as blue dots in the semi log diagram in Figure 6 against thickness of the construction. We also see heavy floating floors without mats (violet dots) and with mats (orange dots) as well as IL for light floating floors on spring supports, or other point supports available on the market (open green dots).

3.4 Details about the best IL data

The heavy floating floor wo mat @ 39 dB and with 50mm mat @ 60 dB is based on a limited IL spectrum from 3-250 Hz provided by a supplier with no reference. The heavy floating floor without mats @ 37-38 dB IL and with 90 mm mat @ 50 dB are based on IL spectra from 1 Hz – 500 Hz measured by an independent acoustics consultant company. With such high insertion loss, the background noise level at the receiver is a problem.

The heavy floating floors with no mats with the lowest performance are screed based and mounted on 8-16mm PUR foam with "waffle" pattern.

3.5 Mat performance

We see that thicker mats perform better than these screed floating floors, but they can of course also be improved somewhat with mats. Most typical mats at 20-30mm have an IL around 18-20 dB. No mat seems to reach up to IL of 40 dBA.

There are weightlifting platforms available with 103 mm multilayer mats based on 70 mm rebound PUR foam and a low bending stiffness floating floor technique including 20mm rubber mats on top of a possibly lossy 12,5mm “technical PUR foam”. Thicker, 120-280mm, “crash mats” are also available.

The best mat IL data in the graph comes from thick shaped underside mats with a softer mat under. Hayne also show in his work that drop tests on a mat mockup and finished laid mats, possibly glued to the floor, give different results [1]. The IL was reduced from 33 dBA for the mockup of two 75 mm playground rubber granulate tiles to just 18 dBA in the completed gym. In plane movements and restrictions may play a role. (Or they bought a thinner version).

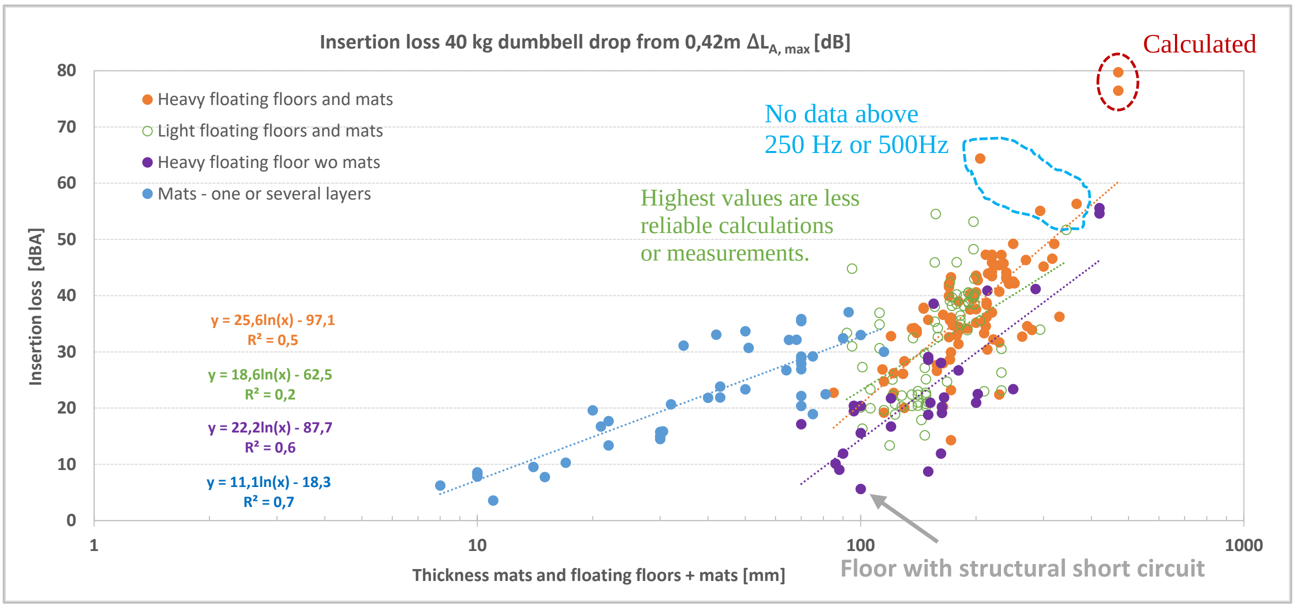

Figure 6: Measured and calculated insertion losses from dumbbell drops on mats, light, and heavy floating floors with and without mats. Some of the highest values comes from limited size mockups with fully vented sides and airspace below. Some of the heavy floor IL data are based on impact reduction data, assuming they perform similarly for a weight drop impact. The source data is a 40 kg urethane covered dumbbell drop 42 cm, or similar.

3.6 Heavy and light floating floor performance

Some of the heavy floating floors with mats perform better here than the light floating floors, but not in the low region around 100-150 mm where they seem to perform about the same. The best data points are for point supported floating floors with thick mats on them. The IL at 55 dBA come from mockups with open (vented) sides and 90 mm of the given thickness is two layers of mats on top. The single dot at 65 dB IL is a spring supported heavy floating floor with a 50 mm mat on it. The very highest two dots are calculated values based on classic vibration insertion loss, including the effect of much increased mass and a 50 mm mat. The model does not include the plate resonances.

4 What noise levels can we expect from gyms?

We have given some raw data for impulses on thin coated concrete floors and mats in Figure 3. The hard raw data can be used in combination with the IL for a mat and a floating floor with a mat from Figure 6 to give expected impact noise levels below the slab, in the room next door and in the same room for manuals.

If we want to predict the noise level at a distance the energy loss and geometrical damping give about 1 dB pr meter loss the first 10 m, a 6 dB per doubling of distance can be expected in addition to higher frequency transmission losses. Up to the next floor we may expect about 15-18 dB transmission loss after which it drops about 3 dB per floor.

A 40 kg manual drop from bench height on a hard floor give about 95 dBA in the same room, below and next door. Dropping it from shoulder height 1,1 m give 100 dBA. A realistic normal cost floating floor solution with a thick mat will damp these impulses to $L_{A,\max}$ = 55 dB and 60 dB, respectively. The very best solution gives $L_{A,\max}$ = 31 dB and 36 dB respectively below and a little less next door for manual drops.

4.1 Noise requirements

In Norway, the noise requirement from service areas in a building with apartments is $L_{A,\ max} \leq 27$ dB. For offices, the limit is $L_{A,\ max} \leq 35$ dB and for workshops and shops it is $L_{A,\ max} \leq 47$ dB. Given the best performing heavy floating floor solution and a good thick mat we will still have 10-15 dB deviation of the noise limit if the gym is above an apartment. If the gym is under the apartment, we will be almost on the good side of the requirement for a 40 kg drop from 1,1 m.

4.2 Comparisons of drop noise levels and requirements

With normal heavy floating floor solution at 40 dB IL with a good mat we will have to set drop energy limits, in order to comply the building regulations (NS 8175:2012). The 30 kg dropped 30 cm is the requirement for one of the large gym companies. They also use 100 kg Olympic barbell dropped 0,9 m in given areas, a drop energy of 884J. If our assumed 15 dB impulse sound level reduction up is sound, the three best solutions are possible, if the gym under apartments is in the same building. If we have the IL = 40 dBA floating floor and mat solution, the maximum allowed drop height for the 30 kg manual will be 5 cm, clearly not a satisfactory solution.

In office buildings the noise limit is $L_{A,\ max} = 35$ dB, 8 dB higher than for apartments. Still the conventional 40 dB heavy floating floor and mat solution is not good enough. But it might work for workshops and shops above the gym.

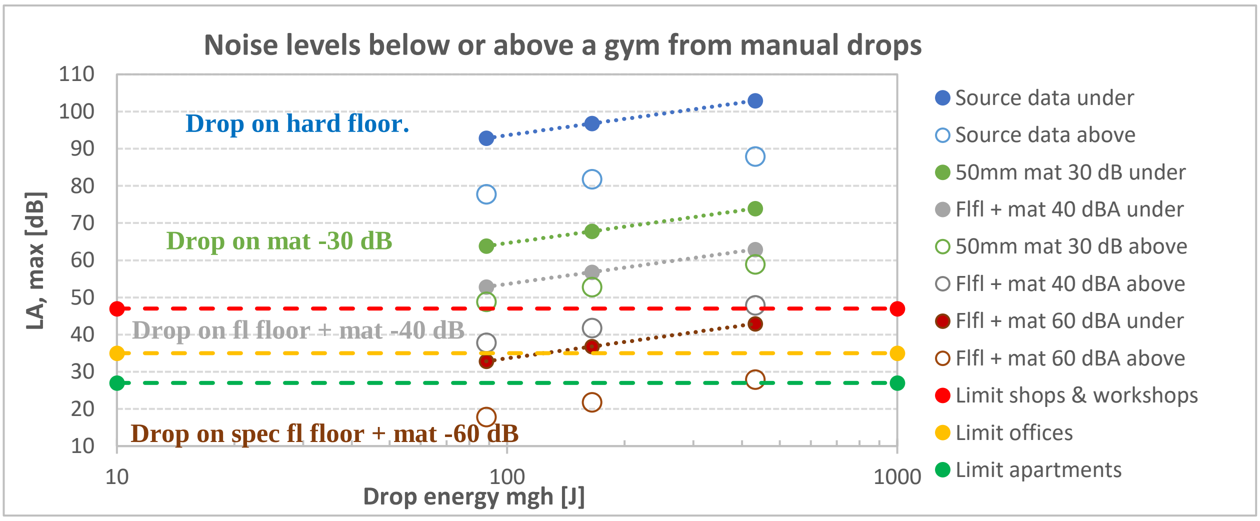

Figure 7: Calculated drop noise levels below and above a gym from 30-40 kg hand manual drops compared to noise limits in NS 8175:2019 for apartments, offices, and shops.

From the assessments here it is quite clear that the noise levels in a building will exceed the noise limits several floors above the gym. 3 dB reduction per floor is not much. Thin mats on 100 mm concrete or less is noticeably noisier than if the thin mat is on a thicker floor slab, in theory about 6-7 dB louder for half the concrete thickness. Even more so for light floating floors. The airborne sound alone can give too high noise levels from impulse drops above a gym if the sound insulation is insufficient. Thick mats can help both airborne and structure born sound.

The quality of the floating floors is extremely important. We see that even a slight failure or “cheap solution” will lead to high risk for making the residents in the building suffer. The Norwegian standard NS 8175:2012 and several of the earlier versions warn against such a combination.

From Figure 7 we see that if a business has room under a gym with free weight training, only the best floor solution with a thick mat will meet the noise requirement. If the business is above the gym, the 40dB regular good heavy floating floor with mat might be a possible solution. Offices and apartments can only lie above a gym. And for apartments, only the best floating floor solution with a ≥ 50 mm thick mat can do the job. The next best solutions @ 50 dBA IL is not good enough.

5 Summary

Typical drop energies in gyms range from a few J up to about 0,6-0,8 kJ from normal to strong lifter use. Failure drops of heavy weights, eg. from squat failures (up to 3,7 kJ) or Olympic lifting overhead may result in drop energies ranging calculated to be up to 2,8 kJ for amateur lifters. The resulting drop force and impact noise depend on the thickness, hardness and nature of the weight and mat, in addition to the drop energy.

Grip plates and hand manuals are typically cushioned 8-20mm with hard rubber or urethane plastic. Bumper plates usually have a 160-220mm rubber core under urethane plastic, just rubber, or rubber granulate, sometimes with some central steel for extra mass. Bumper plate or Olympic bar drops usually will generate lower impact noise levels in dBA than hand manuals for the same drop energy due to more cushioning, and possibly a more complex impact behavior. The weights can be much higher.

We have suggested some reference drop energies and levels from hand manuals and bumperplates. Paired with insertion loss data calculated from IL loss spectra given by suppliers or from own measurements on mats and floating floors, we get a resulting noise level below the floor or above given an assumed structural noise loss upwards limited to about 15 dB, or whatever.

Only solutions with an IL of about 60 dB seem to be about good enough for the heaviest hand manual drops in gyms under apartment buildings. Then still failure drops, or heavy Olympic lifting cannot be accomplished without violating the noise limits. For a more standard 40 dBA solution with a 100-150mm heavy floating floor on 100mm mineral wool and 30-50mm a thick mat, a gym with free weightlifting can lie below shops or workshops, but not offices.

The thicker the mat and the lower the floating floor resonance, the more modal dominant the response in the sender- and receiver rooms. Single number assessments then become more unreliable. Vibrations from weight drops can be perceptible in the floor above. There are no limits for vibrations in apartments in Norway from such activities, only from transport sources. In problem cases the strictest limits in NS8176 have been used, $v_{w,95} \leq 0{,}1$ mm/s. Mats and normal floating floors are not of much help against vibrations, except for possible added damping and share of impulse. Vibration sensitivity in the velocity weighing curves is at their maximum between 4-100 Hz where the resonance frequencies of the floating floors are. Vibrations needs to be addressed in the construction phase, if possible, with a FEA model.

6 Acknowledgements

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7 References

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