

Article

Noise Source Identification in Training Facilities and Gyms

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Abstract: This paper deals with noise problems in industrial sites adapted for commercial training venues. The room acoustics of such an object were analyzed in the scope of the reverberation time and potential acoustic adaptation measures are indicated. Identification and classification of noise sources in training facilities and gyms was carried out based on the acoustic measurements. The influence of rubber padding on impact and noise reduction was investigated in the case of chosen noise-intensive exercise activities performed in a previously described acoustic environment. Potential noise reduction measures are proposed in the form of excitation reduction, vibration isolation, and room acoustics adaptation.

Keywords: noise; impacts; training venues; cross training; functional training; sound pressure level; psychoacoustics



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1. Introduction

The noise, vibrations, and impacts issue in so-called sport and fitness centers is an actual and growing problem. The development of industrialization and globalization has moved a significantly large part of the population to cities. The natural environment for the human body to stay in good physical condition has thus been moved from the physically demanding (relatively) country sides to the comfortable and easy good-access city environment. To counteract the situation of a drop in human body fitness and wellness, the fitness centers business is a developing and growing business branch [1]. Consequently, sport centers in the cities have started to cover a large amount of space. The perfect location for such a place, from the business point of view, is buildings in close vicinity of offices and residential areas.

Another factor is the great rise in the popularity of cross training and functional training fitness centers, where weights are not used in a so-called “quasi-static” way (like in a classic gym). Dynamic ballistic lifts of free weights, box jumps, or slams are commonly performed [1]. Research has proved that heavy concrete floors are characterized by the best performance in the low frequencies but in a wide range of frequencies, damped lightweight floors give the best overall performance [2,3]. In the worst cases, where no proper bumpers and structure protections are adapted, destruction of the load-bearing structure can be observed (Figure 1). This gives a clear picture that the proximity of the heavy weights dropping around offices and residential buildings increases technical and environmental conflict. When “exercise-borne noise” is additionally combined with excessively loud music, which is common in sport centers, this may even result in hearing damage [4].

Torre and Howell [5] reported peak noise levels between 90.5 and 99.7 dB(A) and the overall mean noise level of aerobics classes was 87.1 dB(A), indicating that the music during exercise was the main source of noise. Another study of the noise level during aerobics classes, carried out by Nassar [6], found a mean noise level at 89.6 dB(A). Beach and Nie [4] reported average levels of over 93.1 dB(A) during high-intensity fitness activity. Yaremchuk and Kaczor [7] indicated that noise levels during aerobic classes often exceeded the levels

recommended for occupational noise exposure, with average noise levels ranging from 78 to 106 dB(A). Maffei et al. [8] found that about 20–25% of physical education teachers could achieve a weekly noise exposure higher than 80 dB(A) induced by sport activity and schools. Pękala and Leśna [9] registered sound levels during warm-up without equipment of 50 to 80 dB(A), exercises with balls of 55 to 90 dB(A), team matches of 77 to 93 dB(A), and other activities of 70 to 90 dB(A). More recently, Al-Arja [10] reported the average noise exposure for sports instructors of 92.6 dB(A), and most of the measurement values were above the occupational exposure limit of 85.0 dB(A).

Although the research presented above does present data regarding noise levels during fitness activities, it is not clear how to differentiate between noise caused by music and movement patterns performed by participants. Loud music during exercise can be easily reduced while noise caused by dynamic lifts, box jumps, or slams has not yet been identified nor is it easy to reduce. The localization of sources, acoustics, and vibration isolation in fitness centers should be investigated in three parallel directions: first, structure-borne noise and vibration and its transfer to the surrounding buildings; and second, noise analysis according to common rules and standards to allow legal operation of the sport centers [11,12]. This point proves to be complicated in many countries and regions due to the lack specific standards and test procedures for fitness centers [13]. General test standards for the measurement of room acoustic parameters cover performance spaces [14], ordinary rooms [15], and open plan offices [16]. Kaewunruen and Lei [17] proposed that measurements should be conducted using gym users' smartphones. This enables access to the "real life gym", not disturbed by measurement equipment. However, it is far from any standardized method.

The third direction, although not popular and common in the sport business, is the real psycho comfort [18,19] of the gym users. Psychoacoustics, in comparison to the standard approach, which focuses on the determination of the sound pressure level and absorption of the impact energy or isolation of the vibration and noise energy, defines engineering measurement factors to measure human comfort specifically. The selected factors are listed and described below:

- Loudness—measure of human perception of the sound pressure level with respect to the tone frequency.
- Sharpness—measure of high-frequency tone components in the noise spectrum.
- Booming—measure of low-frequency tones in the noise spectrum.
- Roughness—measure of high-frequency modulation.
- Fluctuation strength—measure of low-frequency modulation.
- Tone to noise ratio—measure of the tonal component with respect to the background/noise.
- Prominence ratio—measure of the characteristic band with respect to defined bands of the background/noise.
- Tonality—measure of the tonal to non-tonal components of noise

Dedicated Olympic weightlifting centers are not located close to offices and residential buildings as now, cross training and functional training fitness centers are more common. The rise in the popularity of dynamic and ballistic movements in these objects requires an assessment of its influence with respect to the dynamic and acoustic phenomena.

The aim of this study was to identify and analyze major sources of noise and shock sources. The measurements taken covered both acoustics and vibrations. The authors present an assessment of the sound pressure level and impact generation on the floor by the selected dynamic and ballistic exercises.

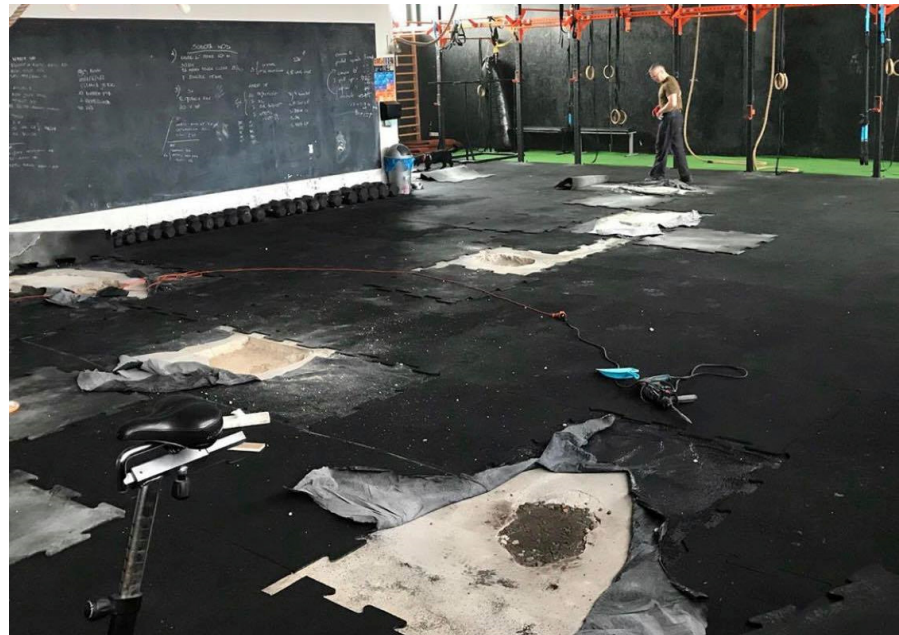


Figure 1. Destroyed fitness center floor.

2. Research Object Description

The acoustic measurements were conducted in a CrossFit box created in an adapted industrial site. The fitness club is part of a terraced warehouse-like building. The main part of the CrossFit box is a 1000 m² open space physical exercise area. The 42 m long, 24 m wide, and 5 m high space is equipped with standard CrossFit box equipment, such as pull-up stations, bikes and rowers, weightlifting platforms, plyo boxes, as well as smaller equipment, such as barbells, kettlebells, dumbbells, medicine balls, etc., placed in racks and custom stands. The open space area is divided into subareas by the group of equipment and the physical activity type to be performed rather than physical barriers, such as walls or enclosures. The only additional construction elements except for the walls, roof, and floor are four pillars supporting the roof structure (Figure 2). The main part of the floor is tiled with 0.02 m thick NBR shore A 75 rubber panels (Figure 3) while other building surfaces are covered with conventional paint. The presented setup is a good representation of an average trending training facility, which can be found all-around the globe.

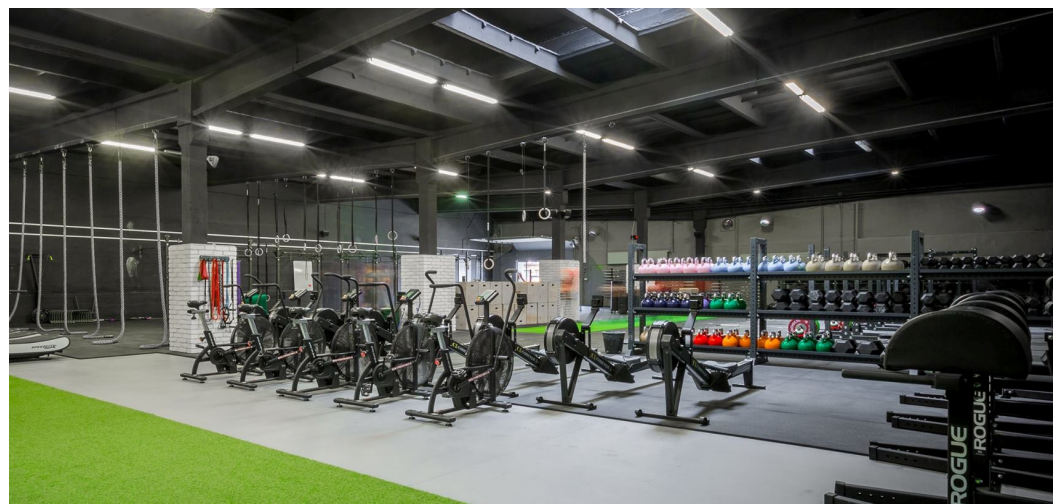


Figure 2. Industrial site adapted to a CrossFit box.

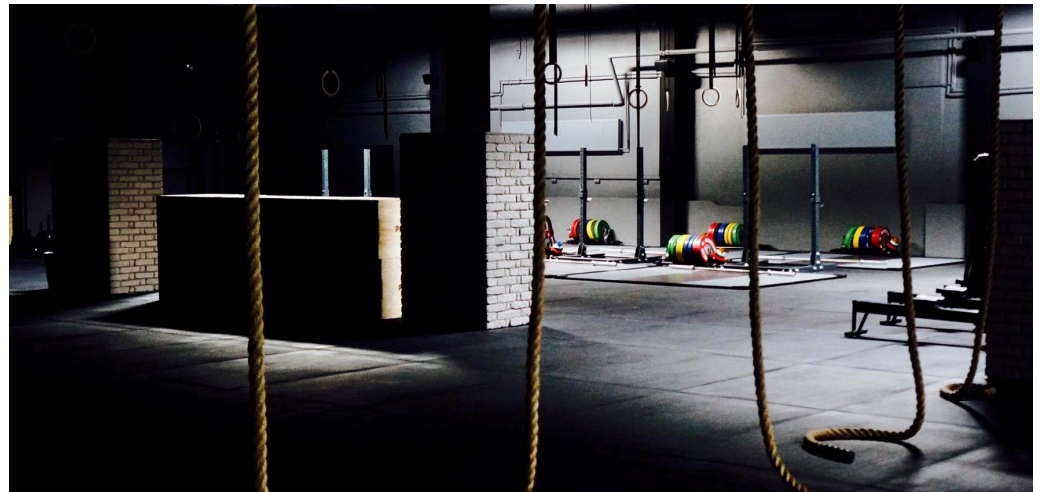


Figure 3. Industrial site adapted to a CrossFit box: weightlifting platforms and plyometric boxes.

Reverberation time measurements were conducted with use of an approximated impulse excitation in the form of a large balloon blast [20] at an unoccupied state. Due to the unusual case/type of enclosure and the preliminary nature of the investigations, a balloon blast was chosen instead of a Dodecahedron speaker due to the ease of use and successful application by other researchers [21–24]. Measurements at six points at the area of physical exercise led to a value of the average reverberation time t_{60} [8,22,23] of 2.95 s. Measurements were conducted in six points, evenly distributed across the training venue. The distance between neighboring points was 10 m, two columns with three rows of points, and the average distance to the nearest wall was equal to 5 m. The averaged sound pressure level decay is presented in Figure 4.

A simple reverberation time calculation was conducted using the Norris–Eyring expression and Fitzroy relationship in order to compare the measured values. Surface acoustic absorption values (Table 1) for the walls, ceiling, flooring, doors, and windows were chosen based on values presented in the literature [25,26]. Noise reduction coefficients NRC were calculated based on the acoustic absorption coefficients at four middle octave band frequencies (250, 500, 1000, and 2000 Hz) for the room’s surfaces, doors, and windows.

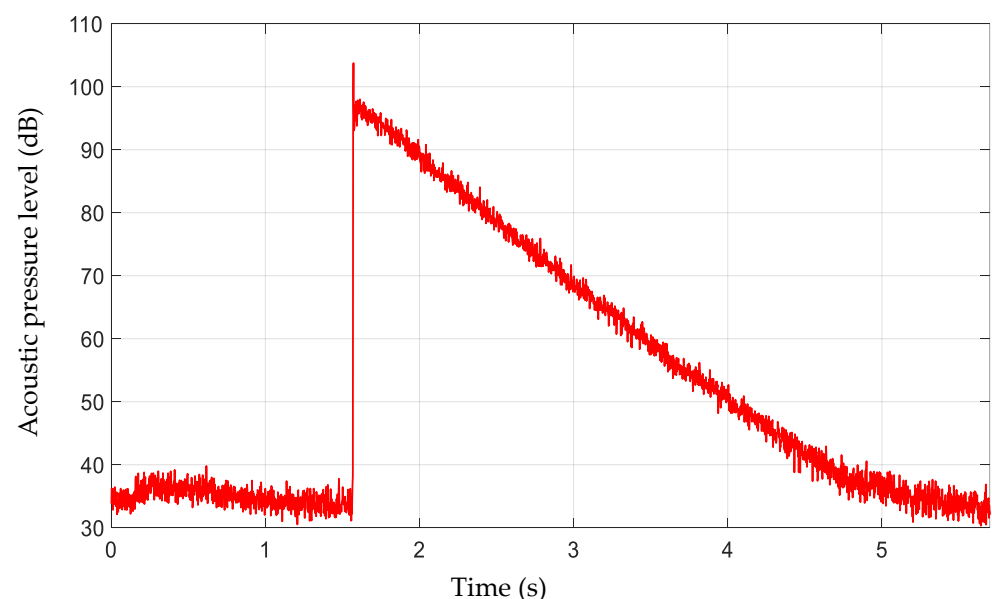


Figure 4. Averaged sound pressure level decay.

Using the Norris–Eyring expression [26], the estimated reverberation time was equal to 33.020 s. The reverberation time calculated with Fitzroy relationship [26] was equal to 33.104 s. The difference between the measured and calculated reverberation time can be caused by differences in sound absorption parameters, geometrical differences of the room, modifications applied to some sections of the roof where additional insulation was introduced, and lastly by the numerous exercise equipment and weightlifting platforms, which introduce additional absorbing surfaces. The reverberation time calculation did not include additional equipment, such as sand bags, medicine balls, rubber and foam components of other fitness devices, bumper plates, and weightlifting platform rubber panels, which can often add some sound absorption to the analyzed room.

Table 1. Material type noise reduction coefficients (NRCs) defined in the calculations.

Surface Name	Material Type	Surface NRC Values
Floor	0.02 m thick hard rubber panels	0.03
Ceiling	Plywood, 5 mm 50 mm airspace filled with glass wool	0.15
Walls	Gypsum panels on studs	0.08
Doors	Wood hollow core door	0.15
Windows	Large panes, plate glass	0.04

3. Identification of the Main Noise-Generating Exercises

Most of the noise and vibration problems in fitness centers and CrossFit boxes have an impact type nature. Heavy weights, such as loaded barbells, impact the flooring as a natural result of the exercise, i.e., Olympic lifts are often dropped from the racked or locked position directly to the ground. Another common cause of heavy floor impact is the dropping of external weight in the form of dumbbells, kettlebells, or barbells due to an improperly executed movement pattern [27] or sloppiness of the trainee. The latter case is quite common during group workouts, where the number of repetitions adds a competitive factor, shifting the focus to the repetitions rather than to proper movement patterns. Combining the above with the presence of multiple club members attending the workout simultaneously, it is common to observe high noise levels, especially during group workouts.

Barbell pulls and lifts as well as plyo box exercises were mentioned by several gym owners and multiple trainees as especially loud exercises. In general terms, the mass and velocity will define the amount of energy that needs to be dissipated during impact, whether it is the external load or the weight of the trainee. A good representation of noise generated during common barbell exercises is the drop of the loaded barbell from the overhead locked position onto the ground. The second investigated case is the drop of the loaded barbell from the overhead locked position onto the plywood jerk blocks presented in Figure 5. Another investigated case is the common drop of a loaded barbell from the locked position of a dead lift onto the floor.

Weights applied to the barbell during measurements were chosen as a representation of the commonly used average weight used during group workouts: 90 kg for deadlifts and 60 kg in the case of other Olympic lifts. Most fitness centers equipped with Olympic barbells use bumper plates similar to the ones presented in Figure 5. Bumper plates have a steel core disc vulcanized in rubber or polyurethane, which increases the durability as well as the impact resistance and presumably reduces the force during impact. The second set of measurements was conducted during box jumps done on a plywood plyometric box, which were identified by users as a noisy exercise.



Figure 5. Weightlifting barbell loaded with bumper plates placed on plywood jerk boxes. Reprinted with the permission of Reference [28]. Copyright 2008 Fringe Sport.

4. Acoustic Measurements

Acoustic measurements were carried out with a class 1 sound level meter. The analyzer microphone was placed at a distance of 2 m from the noise source and a height of 1.5 m, which represents the average spacing between trainees during exercise. Equivalent continuous A-weighted sound level L_{Aeq} and peak sound level L_{Apeak} measurements were carried out over 4 s. Vibration measurements were carried out with a 4 channel 24-bit data analysis system. Acceleration measurements in the vertical direction (perpendicular to the floor surface) were taken simultaneously to the acoustic measurements, with the use of two piezoelectric accelerometers placed in front of the plate impact points directly on the floor, at a distance of 2 m from each side of the barbell. The registered background L_{Aeq} was equal to 48.5.

The first measurements were carried out while a weight lifter performed the jerk part of the clean and jerk lift. The loaded barbell weighting 60 kg was picked by the lifter from the jerk boxes, racked into the clean position, and jerked to the top overhead lockout. From the top position, the barbell was released to freely drop onto the jerk boxes. In the second measurement, it dropped onto jerk boxes with high-density acrylonitrile butadiene rubber padding on the plate landing surface and in the last case, onto the hard rubber-covered floor. Acceleration data acquisition was started by an 0.2 s pre-trigger on one of the accelerometers. Figure 6 presents the sound pressure level decay acquired during each measurement. It can be seen that the highest sound pressure level was registered during the barbell drop onto bare jerk boxes. The acoustic signal decay is lower than in the other measured cases. Due to the hard surface of the plywood and the lack of energy dissipation phenomena, a bar rebound can be observed at around 0.6 s of the measurement, causing a second significant impact excitation on the jerk boxes and an increase in the sound pressure level and the L_{Apeak} was equal to 126.4 dB(A). The application of rubber pads on the top of the boxes resulted in a stronger overall decay of the acoustic signal. The rebounding of the barbell was strongly reduced, which limited additional impacts onto the jerk boxes. The L_{Apeak} was equal to 112.9 dB(A). In the last investigated case, where the barbell was dropped from the overhead locked position directly onto the hard rubber floor, this resulted in the lowest sound pressure levels and slightly better signal decay than in the case of jerk boxes with rubber padding, and visibly better than in the case of bare jerk boxes. Additional impacts caused by rebounds, visible around 0.4 s and 0.6 s, did introduce

an increase of the acoustic pressure level; however, the overall levels were still lower than in other cases, with an LApeak value of 99.0 dB(A).

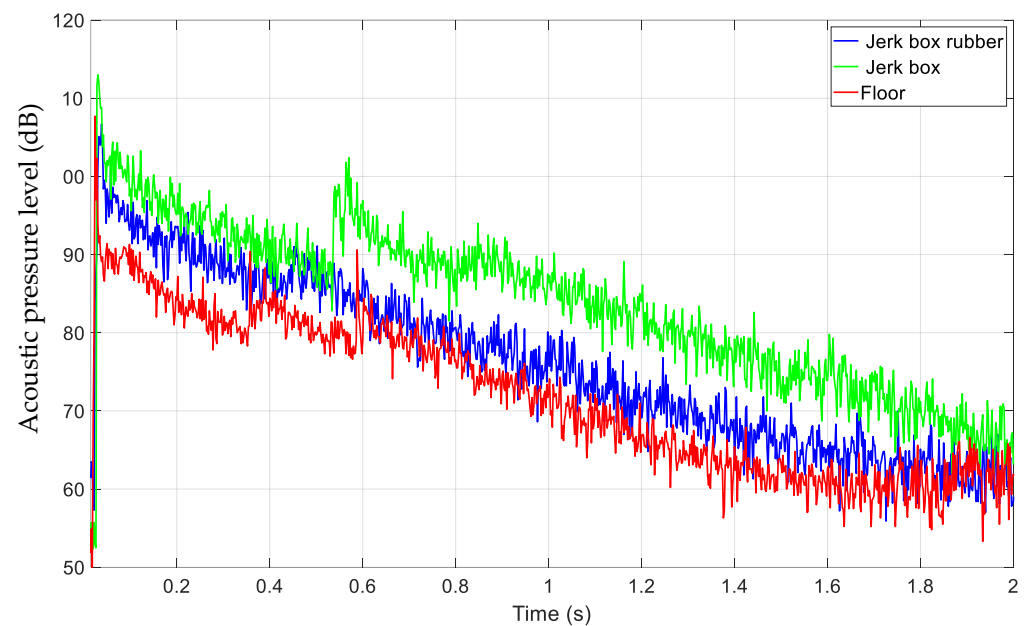


Figure 6. Acoustic pressure level decay registered for different types of barbell impact excitation.

The LAeq value during the drop onto the jerk boxes was equal to 90.5 dB(A). The application of additional rubber padding did reduce the LAeq to 84.7 dB(A), allowing a 5.8 dB(A) reduction. The direct overhead barbell drop onto the rubber flooring of the room generated an LAeq value of 76.6 dB(A).

The acceleration signals acquired simultaneously to the sound pressure are presented in Figure 7. The highest acceleration values are visible in the case of the barbell drop onto the jerk boxes. The application of rubber padding decreased the peak acceleration and reduced the rebounding of the barbell. Counterintuitively, the barbell's impact from the overhead locked position onto the ground corresponded with the lowest acceleration peak values, with visible rebounding of the barbell.

The second set of measurements were carried during a 90 kg barbell deadlift. The acoustic pressure was recorded simultaneously to the acceleration data, as described in the previously discussed measurements. The LApeak and LAeq values were defined for both landing surfaces. The first measurements focused on measuring the acceleration at a distance of 2 m from each side of the barbell. The bar was lifted into the deadlift lockup position from which the barbell was released to drop freely onto the hard rubber flooring, and in the case of the second part of the measurements onto the rubber pads used in previous measurements, placed directly on the rubber floor. Figure 8 presents the influence of the additional rubber padding on the acceleration signals generated during the 90 kg loaded barbell drop. The LApeak was equal to 118.5 dB(A) in the case of the direct floor drop, and 102.8 dB(A) in the case of an additional layer of high-density rubber foam. The additional layer of rubber also strongly decreased the rebounding of the barbell, aiding the decreases in LAeq values.

The LAeq value during a direct drop onto the hard rubber flooring was equal to 79.7 dB(A). The application of additional heavy-density NBR foam reduced the LAeq to 73.1 dB(A), allowing a 6.6 dB(A) reduction.

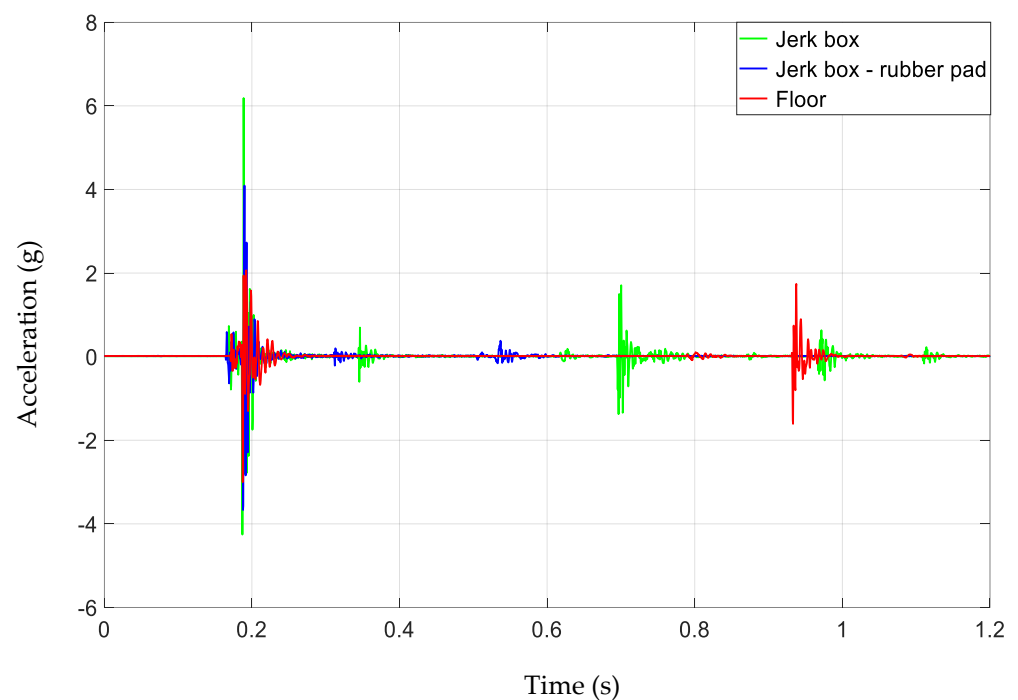


Figure 7. Acceleration generated at the floor during a barrel drop of 60 kg from the overhead locked position.

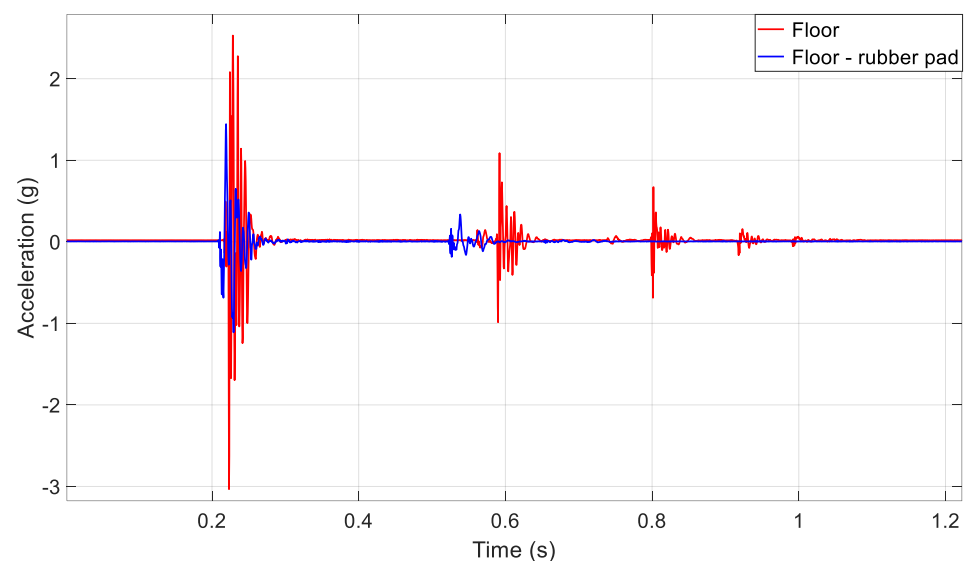


Figure 8. Acceleration generated at the floor during a barrel drop of a 90 kg deadlift barbell drop.

5. Classification of Noise Sources

The acoustic measurements conducted during common exercises chosen based on our own observations are summarized in Figure 9 in each case as an average of three measured occurrences. Acoustic measurements were conducted during barbell drops as in previous present measurements and during a plyometric box jump of an 80 kg trainee, with the height of the plyo box set to 61 cm. All measurements were carried out at a 2 m distance from the source. It can be assumed that the trainees performing the exercises may be exposed to higher levels.

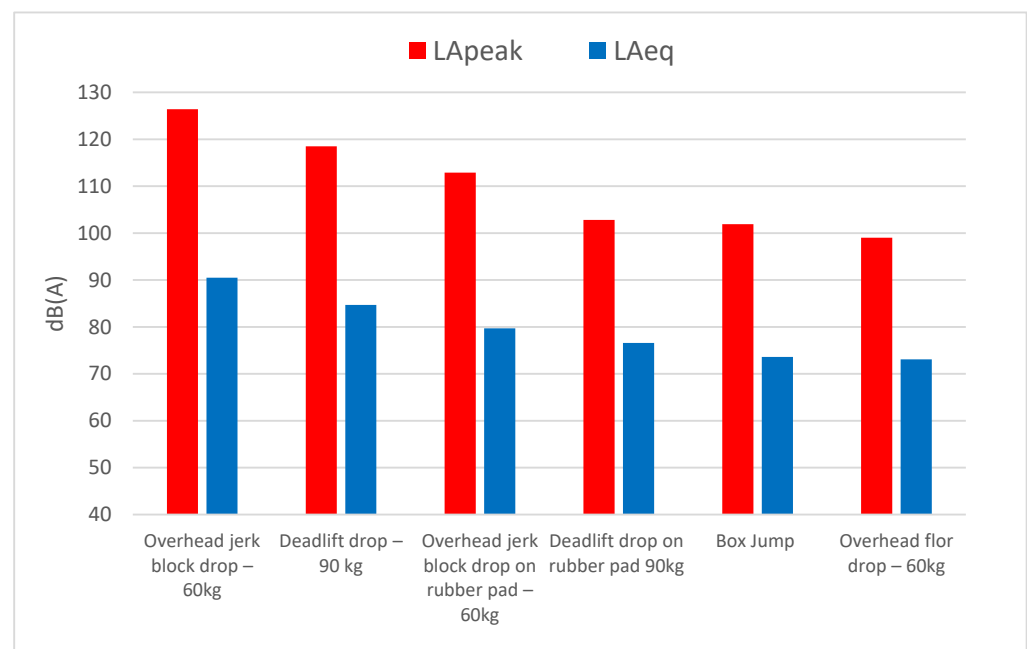


Figure 9. Classification of possible noise sources.

The highest LAeq and LApeak were registered during the dropping of the 60 kg barbell onto the jerk boxes. The second highest levels were observed in the case of the 90 kg deadlift top position barbell drop. The data presented in Figure 9 should be used as an indicator of potential exercises causing increased noise emissions. From the perspective of group workouts, the deadlift should be considered as potentially noisy. Jerk boxes are used mostly by one trainee only, rather than in a group workout session. Deadlifts, box jumps, and snatches or clean and jerks are commonly implemented in group workouts. The legal limit values applicable for this case study are LAeq D < 55 dB(A) A-weighted Leq sound level during the day time and LAeq N < 45 dB(A) A-weighted Leq sound level during the night time.

6. Discussion and Guidelines for Noise Reduction

The presented case is a good representation of an average CrossFit box. The identified and classified noise sources are representative of other similar facilities. It is clear that acoustic levels will differ between enclosures, but the dominant noise sources will remain similar. The conducted measurements indicate potential health hazards can be caused by the investigated exercises. High LApeak values paired with poor room acoustics can potentially have a harmful influence on the wellbeing of trainees as well as reducing the life comfort of other residents, and most certainly can initiate noise-related complains of others or nearby building users. Additional long-term acoustic measurements are needed to fully identify the potential hazards and define their influence on health, comfort, and wellbeing. Acoustic measurements should be carried out over longer exposure times, for example, during an average business day of a training venue.

Noise problems are most effectively solved at the source. All barbell movement patterns investigated above caused excessive noise levels, which could be reduced significantly or even disregarded if the trainee fully controlled each stage of the movement pattern. Dropping of the barbell from locked positions should not take place in the case of light weights, such as ones used during group exercises. The lack of barbell control on the eccentric part of the movement pattern not only compromises the training effects, but also causes the barbells to be dropped onto the ground or training equipment, such as stands or jerk boxes, to cause noise, which should not be emitted in the first place. An additional benefit of proper exercise form is reduced stress on the weightlifting equipment. Proper education on this matter, with an emphasis on the personal benefits of the trainee due to

proper movement form, should be promoted in all facilities equipped with barrels and weights. Plyometric box jump exercises tend to be noisy as well, but in this case, the landing of the trainee on the box is a major part of the exercise and only modification of the plyobox structure and materials can help with noise reduction at the source.

The implementation of acoustic materials with a high absorption coefficient is proven to reduce the reverberation time significantly. This solution is especially suited in the case of large open areas, such as the one presented in Figure 2, where the positioning and possible areas of application of the acoustic material are not limited as in the case of residential buildings and offices.

Vibration isolation is a way to reduce the transmission of excitation signals onto other potential noise-emitting surfaces. Vibration isolation, used in mechanical engineering to reduce vibrations transmitted from the vibration source to other machine elements, devices, or buildings, has been studied by numerous researchers [29,30]. Passive vibration isolation systems in the form of foam or soft rubber [31,32] are used as well as semi-active [33–36] or active ones [33,37,38]. The application of passive vibration isolation as presented in this paper seems to be the best solution for heavy weight-induced impact, due to both economical and practical reasons. Weightlifting platforms equipped with damping materials resistant to mechanical wear, when effective, in many cases are expensive and suited to accommodating one lifer during training, so application for group exercise is especially costly. Areas predestinated for group workouts especially prone to strong and periodic impacts should incorporate additional passive vibration isolation in the form of damping mats.

7. Conclusions

Acoustic adaptation of training areas is especially important in the case of large industrial spaces that have been converted to training centers. A lack of materials and elements with decent absorption coefficients coupled with large room volumes causes long reverberation times. Events, such as the impact of bar plates on the floor, can resonate with the room, causing the sound level to decay slowly, and strongly contributing to the higher equivalent sound pressure levels. This problem should be addressed, especially in the case of long reverberation times combined with multiple impact sources due to group workouts, which contribute to the noise level. The measured acoustic values presented in Figure 9 are induced directly by the physical activity performed by the trainee. Additional noise sources, such as music or other random occurrences, were not present. The registered acoustic values for the specific occurrences range from 73.1 to 90.5 dB(A) in the case of LAeq and 99.0 to 126.4 dB(A) in the case of LApeak. During group workouts, due to multiple active sources, LAeq values are expected to increase, potentially having a negative effect on health.

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