Code of Practice: Managing Flooring Force Reduction Requirements in Multi-Sports and Fitness Facilities

The Health and Fitness Association of Australia

Code of Practice: Managing Flooring Force Reduction Requirements in Multi-Sports and Fitness Facilities

1.1 Rationale

Inadequate flooring in sports and fitness environments significantly increases the risk of injury, especially during exercises involving repeated impact. When the flooring lacks proper shock absorption, it increases the stress placed on joints, muscles, and bones.

The ground reaction forces experienced during exercise can be severe, particularly during high-impact activities. High-impact movements can generate forces nearly twice that of low-impact movements, up to 1.98 times bodyweight (BW) compared to 0.98 BW [1].

The forces experienced during exercises such as running and jumping also increase with greater speed and jump height. Vertical ground reaction forces rise accordingly, placing added stress on the body [2].

When the flooring does not properly absorb these forces, they are transferred directly to the body's soft tissues and joints [25], leading to common injuries like shin splints, tendonitis, and stress fractures [3, 26]. High impact movements also increase the risk of both acute injuries, such as sprains, and chronic joint damage, including cartilage degeneration and osteoarthritis, due to repetitive strain and increased load [3, 27, 9].

Shock-absorbing flooring can reduce the impact forces by decreasing the stiffness of the ground surface [4]. Hard surfaces are associated with higher injury rates compared to shock-absorbing flooring, with evidence showing that injury reports are fewer when appropriate flooring is used [5].

Approximately 75% of fitness professionals instructing high-impact exercise sustain injuries (compared to 22.8%-44% for participants) with the majority occurring in the lower extremities whilst on non-resilient flooring [6, 7]). Up to 73% of all reported injuries among instructors are located in the legs, with the knees and shins being especially prone to damage [5, 6, 7]). One longitudinal study demonstrated 19.8% of instructors were injured once, 69.2% twice and 11% three times. The most frequent site of injury was the leg (33.7%) followed by the knee (27.5%) and the back (22.9%). Tendonitis (22.1%), compartment syndrome (15.6%), low back pain (13.4%), and sprain (16.3%) were the most common diagnoses [9]. The repetitive nature of movements such as jumping and landing places significant strain on the lower body, further highlighting the necessity to ensure that impact forces absorbed by the body during such activities are well managed.

Around 79.5% of injuries sustained by instructors are classified as overuse injuries, largely caused by the repetitive, high-impact movements [9]. Many exceed their limits of tolerance to mechanical impact shock (the forces or shock that the body absorbs during physical activity) in order to maintain high levels of aerobic exercise [8],

Research shows that shock-absorbing flooring can reduce peak ground reaction forces, thereby decreasing joint stress and lowering the risk of musculoskeletal injuries [4].

Sports flooring with higher shock absorption has also been shown to reduce Vertical Instantaneous Loading Rate (VILR) by up to 45%, which is crucial for injury prevention in activities involving repetitive jumping and landing. VILR refers to the rate at which force is applied vertically to the ground during an activity, such as running or jumping. It is a measure of how quickly the force increases when an object or person impacts a surface [13].

The force absorption characteristic of low stiffness flooring (high shock absorption) can also decrease injury rates by reducing the speed and intensity of muscle contractions during impact. Rapid eccentric muscle activity carries the greatest possibility of musculotendinous injury, especially in the lower body muscles controlling joints during impact absorption. If a surface can decelerate the landing of a high velocity (fast, explosive) movement, it reduces the strain on muscles and tendons to generate high-speed tension, thereby preventing injuries [25].

1.2 Purpose

This Code of Practice is designed to provide a comprehensive framework for managing flooring force reduction requirements in Australia's multi-sports and fitness facilities. It aims to improve safety and performance standards by offering guidelines that align with new and existing research, best practices, and available standards. This document serves as a resource for stakeholders to create environments that meet performance and safety criteria conducive to injury prevention for safe physical exercise.

1.2 Scope

This Code of Practice specifically addresses the practical aspects of force reduction and shock absorption for flooring in multi-sport and fitness environments. It focuses on the selection, maintenance, and testing of flooring in these settings. The scope outlines performance criteria, testing protocols, material specifications, and ongoing maintenance requirements to ensure a consistent standard of safety and functionality across facilities.

1.3 Objectives

The objectives of this code of practice are as follows:

- Outline the prevalence, frequency and severity of injuries occurred by fitness instructors due to inadequate flooring.
- Establish a standardised framework for managing flooring systems in multi-sports and fitness facilities to ensure adequate force reduction.
- Reduce the risk of injury and ensure safety for all users, including athletes, staff, and the general public.
- Outline performance requirements and testing methods for shock absorption.

- Ensure consistency in the materials and maintenance of flooring systems across all relevant facilities, improving the quality, safety, and durability of sports and fitness flooring.
- Promote regular performance testing and compliance with specified standards to maintain long-term safety and performance in sports and fitness environments.
- Outline responsibilities for risk assessments, auditing and documentation.

1.4 Applicability

This code of practice applies to all indoor multi-sports and fitness facilities, including but not limited to gymnasiums, sports halls, group exercise studios, functional training areas, dance studios and multi-purpose spaces within Australia. It is relevant to facility managers, flooring installers, architects, contractors, and maintenance personnel involved in the design, installation and upkeep of sports flooring systems, as well as health and safety personnel.

The guidelines within this code must be followed when:

- Selecting materials for flooring systems to ensure compliance with performance criteria.
- Installing new flooring systems or refurbishing existing systems to guarantee adherence to safety and performance standards.
- Performing maintenance, repair, or replacement work on flooring systems to maintain the required safety and performance levels over time.
- Conducting routine or post-installation performance testing to verify compliance with safety and performance benchmarks.

This code is intended to apply to facilities of all sizes and for a range of activities, from recreational use to high-performance sports, ensuring a safe and effective environment for all users.

2. DEFINITIONS AND PERFORMANCE CRITERIA

Existing standards such as ASTM F2772, DIN 18032 and EN 14904 provide specifications for force reduction and shock absorption [14][15][16].

2.1 Shock Absorption

Shock Absorption refers to the ability of a sports flooring system to absorb and dissipate impact forces experienced during physical activity, thereby reducing the force transmitted back to the athlete (force reduction). This helps reduce the risk of both immediate and long-term injuries, especially in high-impact activities.

The mean shock absorption for compliant flooring ranges from **25-75%.** The level of shock absorption should increase with the impact level of the activity. Flooring with a shock absorption rate of 35%-40% may be appropriate for low-impact activities, while high-impact activities require flooring with a higher shock absorption rate, typically 45% or more (see 2.3 for definitions of impact and their appropriate force reduction and vertical deformation ranges).

2.2 Vertical Deformation

Vertical Deformation describes how much the flooring compresses or “gives” under the load of an athlete - the surface will move when load is applied to it.

The human body instinctively adapts to the characteristics of a surface in real time when the foot strikes it. The amount of force exerted and the movement underfoot are critical factors in determining the surface's performance.

The balance between force and movement is essential for both performance and allowing the human body to react effectively to the surface. If vertical deformation is too great, the body may struggle to compensate for the increased force and movement, resulting in greater energy expenditure during activity.

Acceptable vertical deformation ranges between **1.8mm and 5.0mm**, depending on the intensity of the activity, to maintain athlete stability while providing adequate cushioning.

2.3 Definitions of Impact

Low Impact Exercise
Physical activities that exert minimal stress on the joints, typically involving at least one foot in contact with the ground at all times [17]. These exercises reduce the impact forces absorbed by the body, making them gentler on the musculoskeletal system. Low impact exercises involve smooth, controlled movements and are designed to limit jarring or sudden forces that can stress joints and connective tissues [18]. The typical shock absorption range is 25-35 %, with vertical deformation <2.0mm

Moderate Impact Exercise
Physical activities characterised by movements that involve some degree of force on the body, typically with both feet leaving the ground briefly but with less intensity than high impact exercises. These activities involve moderate levels of joint stress and impact, often including activities and movements that are more dynamic than low-impact exercises but less extreme than high-impact activities, such as jogging, light jumping, or bouncing [19]. The typical shock absorption range is 35-45%, with vertical deformation <3.0mm.

High Impact Exercise
Physical activities characterised by movements where both feet leave the ground simultaneously, creating a forceful impact when landing. This impact results in greater stress and shock being absorbed by the bones, muscles, and joints. High impact exercises often involve jumping, running, or rapid directional changes, leading to a higher intensity of movement and increased load on the body's musculoskeletal system. This includes activities that include jumping or hopping, where both feet leave the ground and land with force. Fast-paced movements that involve the body repeatedly impacting the ground with significant force. Exercises designed to produce fast, powerful movements, typically involving explosive jumps or bounds. Movements that involve quick direction changes, causing sudden impact and force on the body [20]. The typical shock absorption range is 45-70 %, with vertical deformation 2.5-5mm.

3. TESTING AND MAINTENANCE

3.1 Testing Procedures and Verification

Testing and verification ensure that sports flooring systems meet the performance criteria specified in this code of practice. This ensures that the flooring can absorb impact forces effectively, protecting athletes from both immediate and long-term injuries. Testing methods must follow the procedures outlined in the appropriate standards

Shock Absorption:

Testing for shock absorption should be conducted using an impact testing device, the *Artificial Athlete Test Apparatus*, which simulates the impact forces experienced by an athlete during activities like running or jumping. **EN 14808** outlines the detailed methodology for conducting this test, including the setup, procedure, and calculation of force reduction to evaluate the shock absorption properties of the surface [21].

The Artificial Athlete device drops a specific weight from a defined height onto the surface. The impact forces are measured, and the reduction in the force transmitted through the floor is calculated as a percentage of the original force applied. This assesses how much force is absorbed by the floor and how much is transmitted back to the athlete. A higher percentage of shock absorption, the more impact is absorbed by the floor, reducing the impact forces experienced by the athlete. This reduces the stress on athletes' joints and muscles, critical for injury prevention.

In accordance with **EN 14904**, a minimum of four tests should be performed, plus one test for every 50m² of flooring. The mean force reduction should range from **25%-75%**, and no individual result should differ from the mean by more than ±5 units (the highest injury rates are observed on flooring with the greatest variability of force reduction magnitudes [22])

The level of shock absorption should correspond to the impact level of the activity the flooring is intended for. Flooring with a shock absorption rate of **25%-40%** may be suitable for low-impact activities, while high-impact activities require a higher shock absorption rate, typically **45% or more**, to effectively mitigate the greater forces exerted during such movements.

Vertical Deformation:

The vertical deformation of the floor should be tested according to **EN 14809**. This ensures that the sports flooring system provides the right balance of flexibility and firmness, reducing the risk of both immediate and long-term injuries for athletes.

Testing involves applying a standard load to the surface using a specialised apparatus, typically simulating the pressure exerted by an athlete's footfall. The test measures the depth of compression in millimetres (mm) to determine the floor's vertical deformation under load.

Acceptable ranges for vertical deformation are **1.8mm to 5.0mm**, depending on the flooring type. This balance ensures comfort and safety while preventing excessive movement that could impair athletic performance.

All testing must be conducted by accredited testing institutes which complies to NATA and ISO17025. One such example in Australia is *Acousto-scan Pty Ltd* (Field Test Institute for AFL/CA, FIH, ITF, FIFA, FIBA WR). The results should be documented in compliance reports that include:

- The results for shock absorption, vertical deformation, ball bounce, and sliding effect.
- Certification of compliance with the performance levels defined by this code of practice.
- Any deviations from these criteria must be addressed, with corrective actions taken where necessary.

These reports should be kept on record by the facility for future audits and maintenance.

3.2 Regular Testing

Flooring materials degrade significantly over time due to environmental factors and regular use. This underlines the importance of regular testing to ensure the flooring continues to meet safety standards [23]

Research supports regular inspections and performance testing of sports flooring systems to ensure ongoing safety and functionality. Monitoring the wear and tear of flooring materials is essential to address degradation caused by high usage [24]. It is recommended that facilities conduct visual inspections every 6 to 12 months and performance testing every 2 to 5 years to maintain compliance with safety standards

- **Initial Testing**: Testing should be conducted immediately after installation to ensure the flooring system complies with all the required performance criteria.
- **Regular Inspections**: Visual inspections should occur every 6 to 12 months**,** especially in high-traffic areas, as part of standard risk assessments. These inspections ensure there are no visible signs of wear, damage, or degradation to identify any potential issues before they impact performance.
- **Performance Testing**: Full performance testing should be conducted approximately every 2 to 5 years**,** depending on the intensity of use and the specific sport.
- Any non-compliance or failure to meet the performance criteria must be addressed promptly through repair, replacement, or further testing, as

required by the provisions of this code.

3.3 Maintenance Programme

A structured maintenance programme is required to ensure the longevity and functionality of sports flooring systems. The maintenance programme should include:

- **Routine Cleaning**: Regular cleaning using appropriate methods and products to remove dust, dirt, and other debris that may affect the floor's performance.
- **Surface Recoating**: Periodic recoating of the surface layer to restore grip, slide properties, and protective finishes as recommended by the manufacturer.
- **Environmental Controls**: Monitoring and controlling the indoor environmental conditions (e.g., temperature, humidity) to prevent damage such as warping, cracking, or material degradation.

3.4 Repair and Replacement

When regular inspections or testing identify performance issues, immediate action should be taken to repair or replace the affected sections. This includes:

- **Minor Repairs**: Small cracks, tears, or worn areas should be repaired as soon as they are identified to prevent further damage and safety risks.
- **Partial Replacement**: If a section of the flooring shows significant wear or damage, it should be replaced while ensuring that the replacement materials meet the same performance standards. Mean force reduction testing must be conducted in this instance to ensure no variability across flooring.
- **Full Replacement**: If the flooring no longer meets the performance criteria outlined in this code, it must be fully replaced to maintain safety and performance.

4. GENERAL REQUIREMENTS

4.1 Compliance

All flooring systems in multi-sports and fitness facilities must comply with the requirements of this code of practice to ensure the safety, performance, and durability of the flooring. Compliance ensures that the flooring meets the minimum thresholds for shock absorption thereby reducing the risk of injury and supporting consistent athletic performance.

Facility managers, contractors, and installers must ensure that:

- The flooring system is tested and certified to comply with the performance classifications outlined in this code of practice.
- Certificates of compliance from the flooring manufacturer must be obtained and documented, confirming that the floor meets the specific requirements for shock absorption.
- Regular inspections and performance tests must be conducted to maintain ongoing compliance throughout the lifespan of the flooring system.

Strict adherence to this code of practice ensures that the flooring provides the necessary safety, performance, and impact mitigation for all users, including athletes, staff, and the general public.

4.2 Documentation

Proper documentation is essential for ensuring compliance with this code of practice and maintaining a transparent record of the safety and performance of sports flooring systems. All relevant data and certificates related to the flooring must be carefully maintained throughout the life of the system. The following documentation must be collected and kept up to date:

Material Specifications and Activity Documentation:
The manufacturer, supplier, architect, or contractor must ensure that the correct materials are specified for the flooring, based on all available information, including available standards and performance requirements. The flooring must be chosen to suit the specific activities for which it will be used, ensuring optimal safety and performance. Documentation **must** be maintained from the time of installation, clearly outlining the activities specified for use on the flooring. This documentation must be kept on record for future reference to confirm the suitability of the flooring for its intended purpose.

Certificates of Compliance: Upon installation, the flooring manufacturer must provide certification that the flooring system meets all the performance criteria outlined in this code of practice. These certificates should include:

- The specific test results from accredited testing bodies.
- Details of the testing methods and code used to verify compliance.

Performance Test Reports: Documentation of all performance tests conducted during installation and at subsequent intervals (e.g., every 2-5 years). These reports should detail:

- The conditions under which the testing was performed (e.g., environmental factors).
- The results for a minimum of four tests, plus one test for every 50m² of flooring.
- Any corrective measures taken if performance falls below the required thresholds.

Inspection Records: A log of all routine inspections, typically conducted every 6-12 months, must be maintained. These records should detail:

- The condition of the flooring (e.g., signs of wear, damage).
- Any repairs or maintenance actions taken as a result of the inspections.

Maintenance Logs: Records of any maintenance, repairs, or replacements performed on the flooring system should be kept, specifying the nature of the work, the materials used, and the date of completion.

Audit Reports: Compliance audits should be conducted periodically to ensure that all testing, inspection, and maintenance activities are performed in line with this code of practice. Audit reports should summarise:

- The results of the audits.
- Recommendations for further action, if necessary.

4.3 Safety and Performance

Ensuring the safety and performance of sports and fitness flooring systems is central to the objectives of this code of practice. Flooring systems must be designed, installed, and maintained to meet the specified criteria for impact absorption, stability, and functionality, reducing the risk of injury and enhancing athletic performance. The following key aspects must be adhered to:

- **Safety**: Flooring systems must prioritise athlete safety by ensuring that the surface mitigates impact forces, prevents slips, and provides adequate support for movement. This includes compliance with the force reduction requirements of this code to minimise the risk of injuries.
- **Activity Use**: The flooring must be chosen to suit the specific activities for which it will be used at the time of installation. At no point should the flooring be used for activities for which it was not originally intended.
- **Performance**: The flooring must provide consistent and reliable performance over its lifespan.
- **Longevity and Durability**: Flooring systems should be designed to withstand the expected level of traffic and use over time. Materials used in the flooring must offer durability to prevent early wear and tear that could compromise

safety or performance. Regular maintenance and prompt repairs must be carried out to address any degradation.

4.4 Quality Assurance

Maintaining high standards of quality is critical to ensuring the long-term performance and safety of sports flooring systems. This code of practice outlines a comprehensive approach to quality assurance, encompassing every stage of the flooring's lifecycle, from material selection and installation to ongoing maintenance and performance verification.

- **Pre-installation Inspections**: Before installation, all flooring materials must be thoroughly inspected and selected to ensure they meet the specific performance requirements for the intended activity. This includes verifying that the materials have been tested and certified by accredited testing bodies, in line with the performance requirements outlined in this code.
- **Installation Quality Control**: During installation, flooring contractors must adhere to best practices to ensure the correct laying and finishing of the sports flooring system. Quality checks must be carried out throughout the installation process to verify that the substrate is properly prepared, that all layers of the flooring are installed correctly, and that the environmental conditions (e.g., temperature, humidity) are suitable for installation.
- **Post-installation Testing**: Once installation is complete, performance testing must be conducted to verify that the flooring system meets the required performance criteria. Any deviations from the required results must be addressed immediately.
- **Ongoing Monitoring**: A quality assurance program should include routine inspections and performance tests at regular intervals (every 6-12 months for inspections and every 2-5 years for full performance testing is recommended). This helps ensure that the flooring system continues to meet the required safety and performance standards over its lifespan. Documentation of these inspections and tests should be maintained for future audits.
- **Certification and Audits**: Flooring systems must be certified for compliance with this code of practice, and regular audits should be conducted to verify that all aspects of the quality assurance process are being followed. Audit reports should be prepared, detailing any discrepancies or areas for improvement and outlining any corrective actions that have been taken.

By implementing a robust quality assurance process, facility managers and contractors can ensure that sports flooring systems provide safe and high-performance environments for athletes, while also maximising the longevity and durability of the flooring system.

5. MATERIAL SPECIFICATIONS

5.1 Approved Materials

Available standards (*EN 14904, ASTM F2772, DIN 18032*) provide guidance on the types of materials that are suitable for sports flooring systems, focusing on area-elastic, point-elastic, mixed-elastic, and combined-elastic systems.

However, these standards do not encompass every type of sports flooring. Alternative options, such as turf or artificial grass surfaces, custom or hybrid sprung wooden floors (e.g., adjustable or modular spring systems), and portable flooring, may also be used. These alternatives must still comply with the performance requirements outlined in this code and be appropriate for the specific activities conducted on them.

The manufacturer, supplier, architect, or contractor must ensure that the correct materials are specified for the sports flooring, based on all available information, including available standards and performance requirements. The flooring must be chosen to suit the specific activities for which it will be used, ensuring optimal safety and performance. Documentation **must** be maintained from the time of installation, clearly outlining the activities specified for use on the flooring. This documentation must be kept on record for future reference to confirm the suitability of the flooring for its intended purpose.

Area-Elastic Floors

Area-elastic floors distribute impact forces over a wide surface area. These floors are highly suited for sports where a uniform distribution of impact is critical for athlete safety and performance. The flooring structure flexes and distributes energy over a larger area, minimising concentrated stress on the body.

Materials Used:

- **Wood**: Maple and oak are common materials used for sprung wooden floors. These woods are durable, stable, and provide a consistent playing surface. The wood surface is supported by an underlying elastic substructure, often made from rubber pads, foam, or elastomeric components, which allow the floor to flex.
- **Engineered Wood**: Consisting of layers of wood veneer, engineered wood provides the same aesthetic benefits as solid wood but offers improved stability, making it more resistant to warping due to moisture or temperature fluctuations.
- **Substructure Materials**: The elastic underlayer is critical to distributing impact forces. This typically consists of foam pads, elastomeric layers, or rubber mounts, which provide resilience and help distribute impact across a larger surface.

Point-Elastic Floors

Point-elastic floors absorb impact at the point of contact, creating localised cushioning where the force is applied. The floor deforms primarily at the impact site, providing high levels of shock absorption directly beneath the foot.

Materials Used:

- **Rubber**: **Natural or synthetic rubber** is widely used for point-elastic floors. Rubber is highly durable, resilient, and provides excellent slip resistance, making it suitable for high-impact environments. It also offers strong localised shock absorption.
- **Vinyl**: **Foam-backed vinyl** is another popular option for point-elastic systems. Vinyl provides a cushioned, resilient surface that effectively absorbs impact at the point of contact, while also being resistant to moisture and easy to maintain.
- **Polyurethane (PU)**: **Polyurethane** flooring consists of a seamless top layer over a resilient base (usually rubber or foam). PU floors are highly versatile and provide point elasticity, making them suitable for a variety of sports activities. The surface can be tailored by adjusting the thickness of the PU and foam layers.

Mixed-Elastic Floors

Mixed-elastic floors combine the properties of both point-elastic and area-elastic systems, offering a hybrid solution. These floors provide a balance between distributing impact forces across a wider area (area-elasticity) and absorbing forces at the point of impact (point-elasticity). This combination makes them highly adaptable and suitable for various types of athletic activities.

Materials Used:

- **Combination of Wood and Synthetic Materials**: Mixed-elastic systems typically feature a point-elastic top layer**,** such as foam-backed vinyl or rubber, laid over an area-elastic substructure (e.g., wood or foam). The point-elastic layer provides localised cushioning, while the area-elastic substructure helps distribute forces across the surface.
- **Multi-layer Synthetic Systems**: In some cases, mixed-elastic floors may consist entirely of synthetic layers that provide a combination of properties. For example, a polyurethane top layer might be paired with an elastic substructure of foam or rubber to achieve mixed-elasticity.

Combined-Elastic Floors

Description: Combined-elastic floors (also referred to as combi-elastic floors) incorporate both area-elastic and point-elastic elements into a single system. These floors provide a stable, resilient surface that distributes force over a wide area (via the area-elastic substructure) while also absorbing impact at specific points (via the point-elastic top layer). This combination makes them suitable for a wide range of sports and activities.

Materials Used:

- **Wood and Synthetic Combinations**: Combined-elastic systems typically feature an area-elastic substructure, such as a sprung wooden floor or engineered wood, combined with a point-elastic top layer, like rubber or vinyl. This creates a floor that can effectively handle both broad force distribution and localised impact absorption.
- **Polyurethane with Elastic Underlayers**: A common configuration for combi-elastic floors involves a polyurethane (PU) surface laid over a rubber or foam underlayer. This allows for both high durability and combined shock absorption properties.

5.2 Certification

All materials used in the flooring system must be certified by an accredited testing body to verify compliance with the performance criteria established in this code of practice. Certification must confirm that the materials meet or exceed the required thresholds for shock absorption, vertical deformation, ball bounce, and sliding effect. This certification should be:

- Provided by the manufacturer prior to installation.
- Included as part of the documentation to be maintained throughout the flooring's lifespan.

5.3 Material Testing

All materials used in the flooring system must undergo testing prior to installation to ensure they meet the required shock absorption performance standards. This testing should adhere to the methods outlined in the appropriate standard (ie EN14808).

5.4 Durability and Maintenance

The materials used in the sports flooring system must be durable enough to maintain their performance characteristics over time, even under heavy use. This includes resistance to wear, impact, and environmental factors such as humidity and temperature fluctuations. A regular maintenance schedule must be established to preserve the flooring's durability and functionality, including:

- Regular cleaning to prevent the build-up of dust and debris that could affect performance.
- Routine inspections to identify any signs of wear or damage, and immediate repairs where necessary.
- Recoating or resurfacing as recommended by the manufacturer to prolong the life of the flooring system.

[1] Ricard, M. D., & Veatch, S. (1990). Comparison of impact forces in high and low impact aerobic dance movements. *International Journal of Sport Biomechanics*, 6(1), 67–77.

[2] Ricard, M. D., & Veatch, S. (1994). Effect of running speed and aerobic dance jump height on vertical ground reaction forces. *Journal of Applied Biomechanics*, 10(1), 14–27.

[3] Coburn, S. L., Crossley, K. M., Kemp, J. L., & Ozturk, H. (2023). Immediate and delayed effects of joint loading activities on knee and hip cartilage: A systematic review and meta-analysis. *Sports Medicine - Open*, 9(56). https://doi.org/10.1186/s40798-023-00602-7

[4] Drahota, A., Felix, L. M., Keenan, B. E., Lachance, C. C., Laing, A., Mackey, D. C., & Raftery, J. (2020). The SAFEST review: Shock-absorbing flooring effectiveness. *BMJ Open*, 10(2), e032315. https://bmjopen.bmj.com/content/10/2/e032315

[5] Carroll, J. (1988). Injuries in low-impact and high-impact aerobic dance: A preliminary survey. *American Fitness*, 6(4), 1–5.

[6] Mutoh, Y., Sawai, S., Takanashi, Y., & Skurko, L. (1988). Aerobic Dance Injuries Among Instructors and Students. *The Physician and Sportsmedicine*, *16*(12), 81–86. https://doi.org/10.1080/00913847.1988.11709665

[7] Richie, D. H., Kelso, S. F., & Bellucci, P. A. (1985). Aerobic Dance Injuries: A Retrospective Study of Instructors and Participants. *The Physician and Sportsmedicine*, *13*(2), 130–140. https://doi.org/10.1080/00913847.1985.11708751

[8] Francis, L. L., Francis, P. R., & Welshons-Smith, K. (1986). Aerobic dance injuries: A survey of instructors. *Journal of Occupational Medicine*, 28(6), 131–139

[9] Malliou, P., Rokka, S. T., Tsigganos, G., Mavromoustakos, S., & Godolias, G. (2013). Profile of dance aerobic instructors' injuries, part I. *Journal of Human Sport & Exercise*, 8(3), 806–812.

[10] Blackmore, T., Willy, R. W., & Creaby, M. W. (2016). The high frequency component of the vertical ground reaction force is a valid surrogate measure of the impact peak. Journal of Biomechanics, 49(3), 479-483. https://doi.org/10.1016/j.jbiomech.2015.12.019

[13] Malisoux, L., Gette, P., Urhausen, A., Bomfim, J., & Theisen, D. (2017). Influence of sports flooring and shoes on impact forces during jump tasks. *PLOS ONE*, 12(10), e0186297. https://doi.org/10.1371/journal.pone.0186297

[14] ASTM F2772-11. (2011). *Standard specification for athletic performance properties of indoor sports floor systems*. ASTM International. https://doi.org/10.1520/F2772-11

[15] DIN 18032-2:2001: Sports halls - Halls for gymnastics, games and multi-purpose use - Part 2: Floors requirements and testing.

[16] EN 14904. (2006). *Surfaces for sports areas - Indoor surfaces for multi-sports use - Specification*.

[17] Palinski-Wade, R. (2023). Low-impact exercise: Benefits, types, tips, and more. *Verywell Health*. https://www.verywellhealth.com/low-impact-exercise-5196402

[18] Koszuta, L. E. (1986). Low-impact aerobics: Better than traditional aerobic dance? *The Physician and Sports medicine*, 14(7), 156–161. https://doi.org/10.1080/00913847.1986.11709132

[19] MacIntosh, B. R., Murias, J. M., & Keir, D. A. (2021). What is moderate to vigorous exercise intensity? *Frontiers in Physiology*, 12, Article 682233. https://www.frontiersin.org/articles/10.3389/fphys.2021.682233/full

[20] Feito, Y., Heinrich, K. M., Butcher, S. J., & Poston, W. S. C. (2018). High-intensity functional training (HIFT): Definition and research implications for improved fitness. *Sports*, 6(3), 76. https://doi.org/10.3390/sports6030076

[21] EN 14808. (2005). Surfaces for sports areas - *Determination of shock absorption*

[22] Hopper, L. S., Allen, N., Wyon, M., Alderson, J., & Elliott, B. (2014). Dance floor mechanical properties and dancer injuries in a touring professional ballet company. *Journal of Science and Medicine in Sport*, 17(1), 29–33. https://doi.org/10.1016/j.jsams.2013.02.009

[23] Coelho, P., Silva, A., & de Brito, J. (2021). How long can a wood flooring system last? *Buildings*, 11(1), 23. https://doi.org/10.3390/buildings11010023

[24] Kim, S., Shin, H.-O., & Yoo, D.-Y. (2020). Mechanical and dynamic behavior of an elastic rubber layer with recycled styrene-butadiene rubber granules. *Polymers*, 12(12), 3022. https://doi.org/10.3390/polym12123022

[25] Hackney J, Wilcoxon S, Holtmeier M, Eaves H, Harker G, Potthast A. (2023). Low Stiffness Dance Flooring Increases Peak Ankle Plantar Flexor Muscle Activation During a Ballet Jump. *Journal of Dance Medicine & Science,* 27(2):99-106. doi:10.1177/1089313X231177180

[26] Malisoux, L., Gette, P., Urhausen, A., Bomfim, J., & Theisen, D. (2017). Influence of sports flooring and shoes on impact forces and performance during jump tasks. *PLOS ONE, 12*(10), e0186297. https://doi.org/10.1371/journal.pone.0186297