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Final report

Test of Ollov shoe versus standard iron shoe on different surfaces

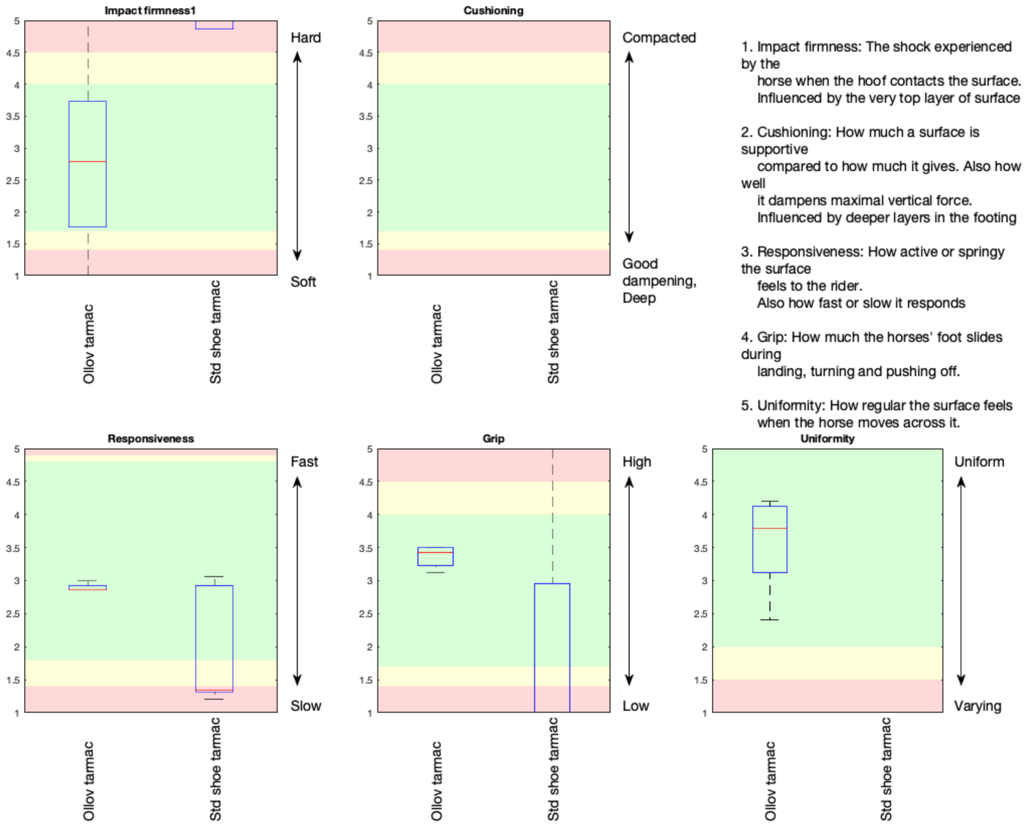
The Orono Biomechanical Surface Tester (OBST) was used with attachment of an Ollov shoe and an 8 mm iron shoe respectively. Tests were performed on 6 different surfaces. The OBST is a wellproven and known equipment to quantify properties of equestrian surfaces, and has been used for mechanical testing of several equestrian Olympic arenas as well as World Equestrian Games.

The OBST mimics loads and velocities for a 600 kg horse during landing after a fence. It measures five different properties that are assumed to be important and relevant for the horse in relation to the ground. Impact firmness, Cushioning, Responsiveness, Grip and Uniformity. Attaching different shoes to the OBST will reveal differences in how a horse would be affected by the different shoes.

Main result:
Especially on hard surfaces the Ollov shoe attenuates vertical impact decelerations of the hoof compared to an iron shoe. This is comparable to lowering impact firmness of the ground. **Another way to explain it is that it lowers the forces that the horse is exposed to at the very moment that the hoof touches the ground.**
On all other grounds there were different degrees of lowered maximal vertical load with Ollov compared to iron. **This means that the maximal load that occurs at midstance, approximately when the limb is vertical is lowered. It is assumed that this is important to minimize risk of orthopedic injuries.**

Specific findings on different grounds
Below are specific findings on different grounds presented. Ollov shoe is compared in boxplots with an 8 mm iron shoe. The green, yellow and red bands represent thresholds used by FEI in international championships and does not mean that red is generally bad or unacceptable just not acceptable for top level show jumping arenas. Focus should be on the comparison between Ollov and iron shoe when examining graphs.
More details about the measuring technique used can be found in the appendix and more literature can be found in the following places.
http://www.fei.org/system/files/Equestrian_Surfaces-A_Guide.pdf
http://www.fei.org/system/files/Equine%20Surfaces%20White%20Paper.pdf

Tarmac:



General explanation to the graphs. The five parameters are normalized to an 1 to 5 scale based on what we see in high level international Show Jumping arenas. This is the reason that in some cases some values are out of range since it is simply not the kind of surface properties that you would expect at these arenas. The colored bands represent what a majority of top riders would find acceptable/good (green area), less than good (yellow area) and poor/not acceptable (red area) on a high level competition arena. In this case these areas are not primarily important for the results but instead the comparison between the Ollov and iron shoe. In other words focus should be on the relative comparison between these two shoes.
The plots show results from at least 6 test measurements on each surface and shoe respectively. The red line is the median value of the six or more measurements, the blue box encompasses the mid 50% of the measurements and the whisker is the absolute max and mean values. This means that you should start comparing the level of the red lines to interpret if there is a difference between the two shoes. It is also important to look at the height and whether there is an overlap between the two boxes in the comparison. A high box means large variation and overlap/large overlap means that there is likely no significant difference between the two shoes, even if the red lines are on different levels.

Ollov very clearly lower impact firmness of the ground (lowered by 70 %, 243 g to 72g). This makes sense since this parameter represent impact (the fast deceleration of the hoof at first contact with the ground) and the rubber with its give is likely to dampen this deceleration.

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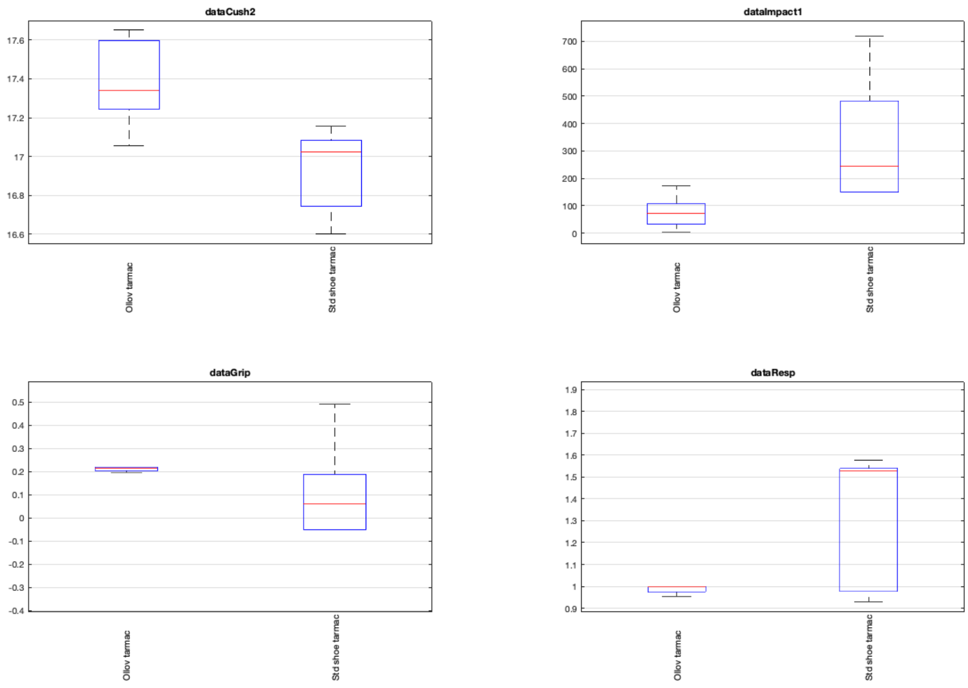
Cushioning is very high with both shoes with a slightly higher value (2%) for Ollov compared to iron shoe. It is out of range in this graph, which just represents the fact that you would not choose this surface for Show Jumping. This is logical since tarmac is extremely compacted and the reason for a higher value for Ollov can only be speculated on in this case. A plausible cause would be a timing of rebound in the rubber material that is “out of phase” and thus could increase load. Cushioning represent damping of maximal load and from a surface point view the compaction of deeper layers in the surface.

Responsiveness has a much higher variation (the blue box is much higher, 46% higher) for iron shoe. Interestingly Ollov seem to lower this variation, which is quite logical and likely due to the rubber material simply attenuating variation.

Grip is slightly higher and less varying with the Ollov compared to iron, which would be expected since iron shoes can be rather slippery on tarmac (low degree of friction between two hard and flat surfaces). Iron shoe is also below what is accepted for show Jumping

Below a graph with absolute values.



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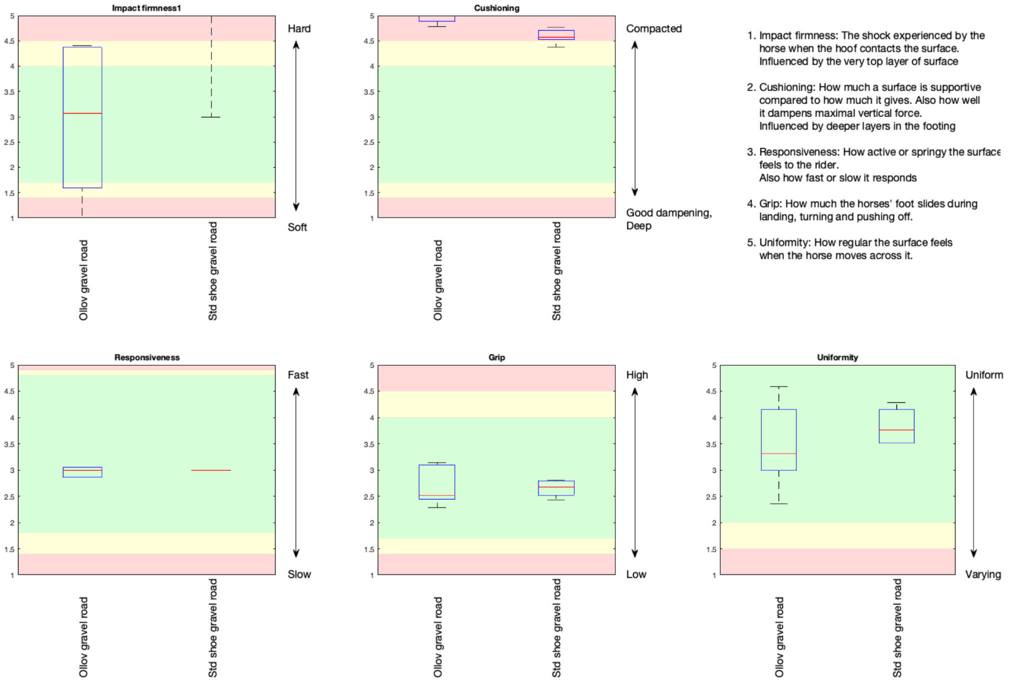
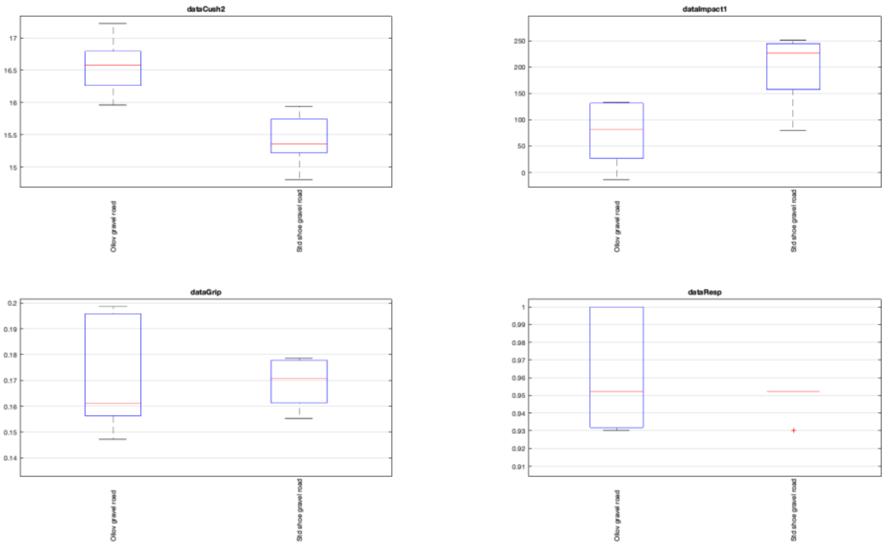
Gravel road:



Basically the same findings as on the tarmac just a little bit less pronounced (Impact firmness lowered 63%). The grip does not differ substantially here though

Below a graph with absolute values.



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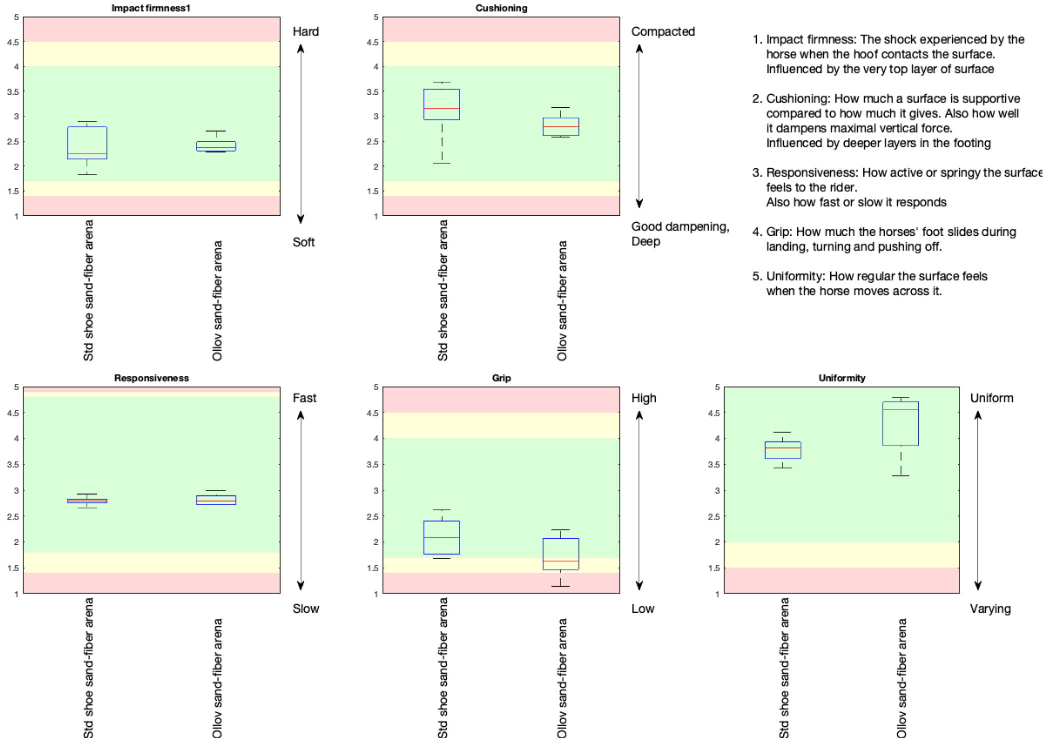
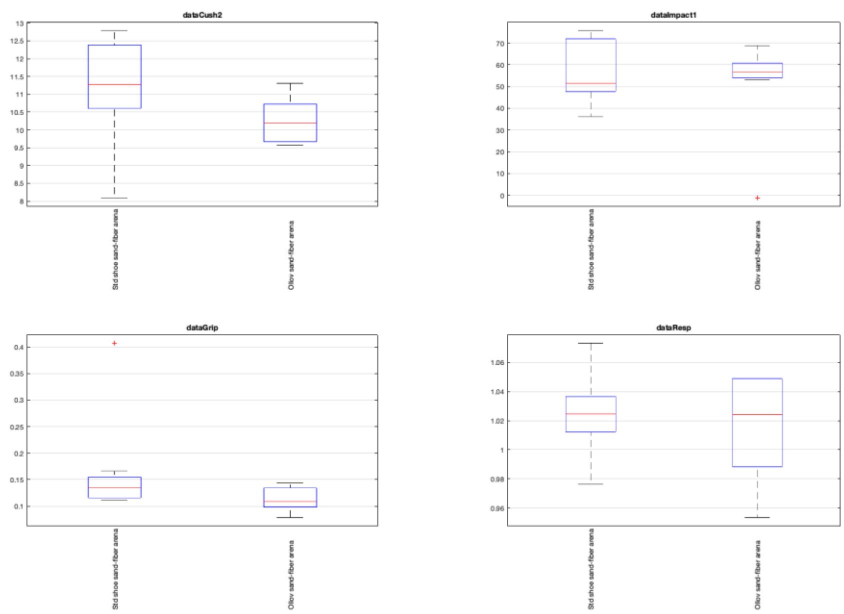
Fiber-Sand arena:



In and arena like this with a lower impact firmness you would not expect to see any effect of the rubber in the Ollov shoe and that is also the case. Very interestingly you seem to have lowered cushioning with Ollov compared to iron shoe on this arena (10%). This is a substantial lowering of maximal load that the horse would be exposed to during midstance. Apart from this no other clear differences

Below a graph with absolute values.



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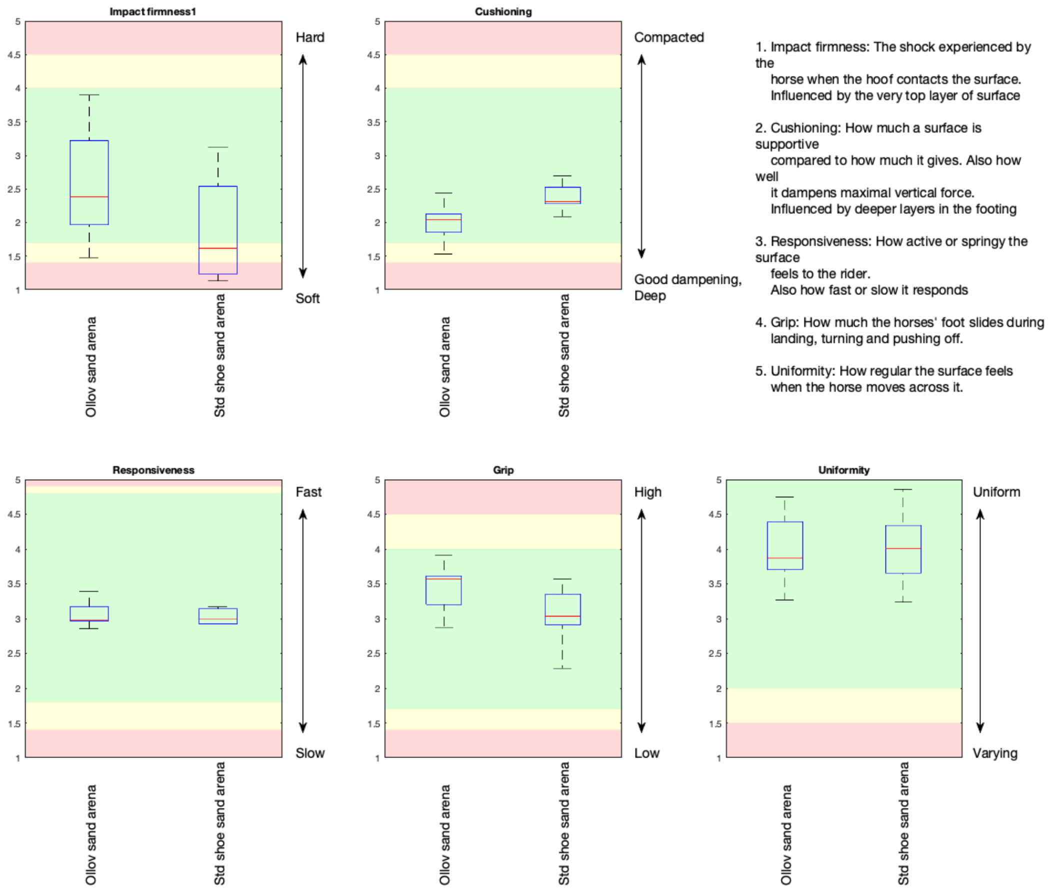
Sand arena:



The pattern is very similar to the sand-fiber arena (8% lowering of Cushioning/max load with Ollov)

Below a graph with absolute values.

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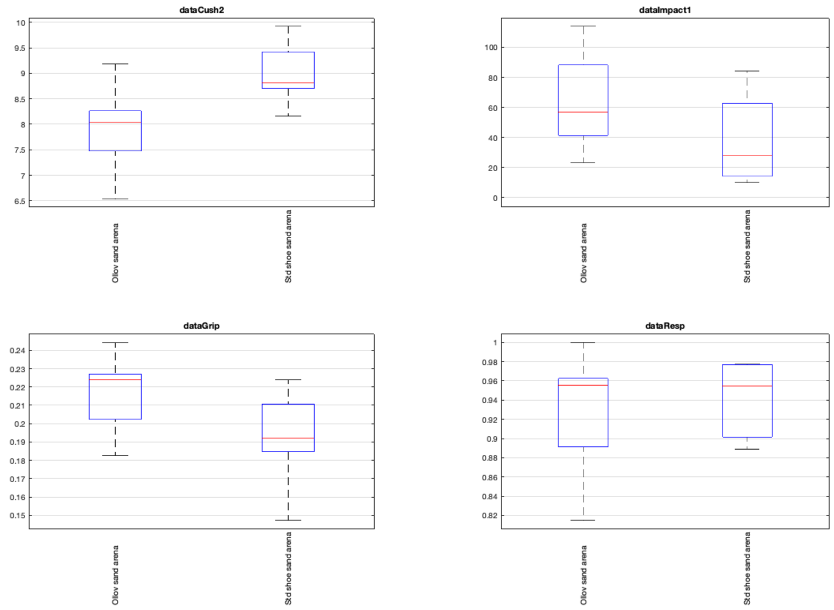
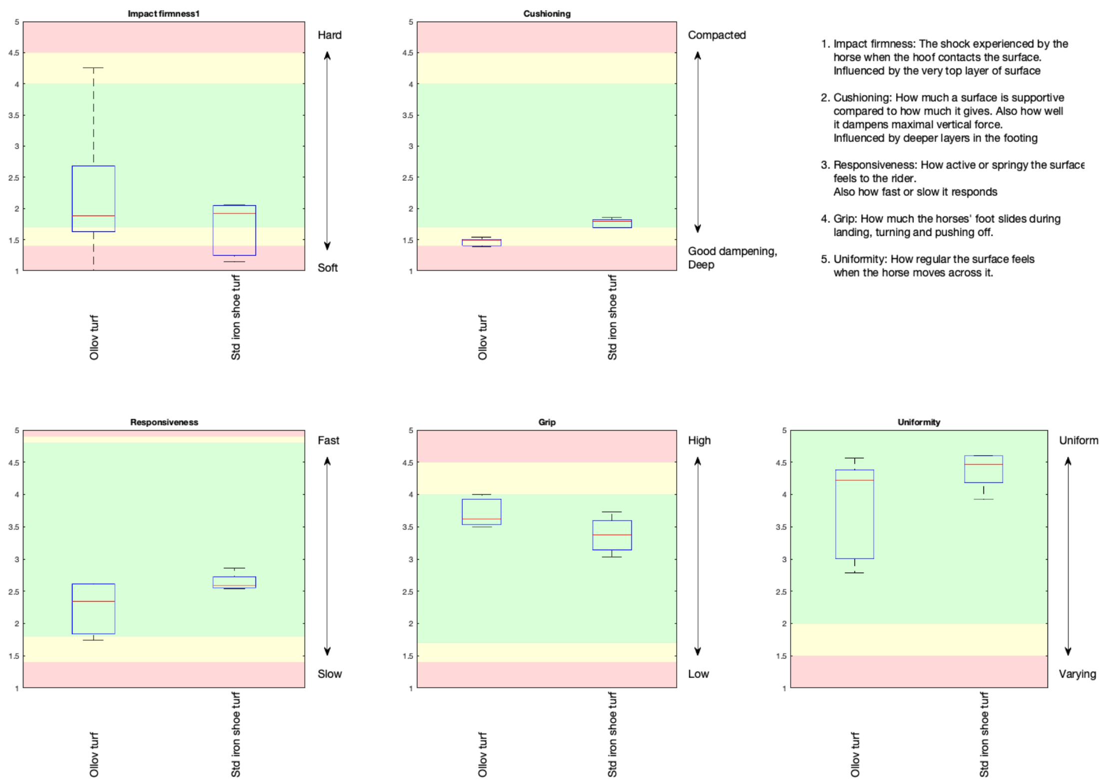


Turf:



The turf in itself has substantially lower both impact firmness and cushioning due to more compliant properties. The turf tested was to the “softer” side. Grip was higher due to the hoof penetrating into the ground and thus being horizontally decelerated. Interestingly you

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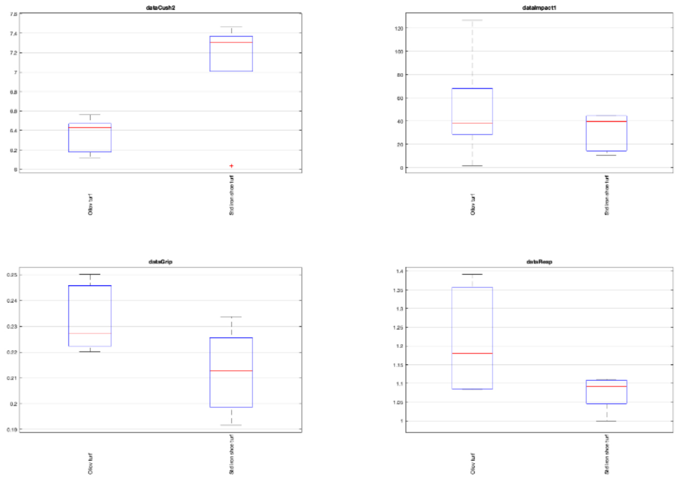
still as with fiber-sand see a small but significant lowering of cushioning (12% better dampening of max load) with Ollov compared to iron shoe.

Below a graph with absolute values.



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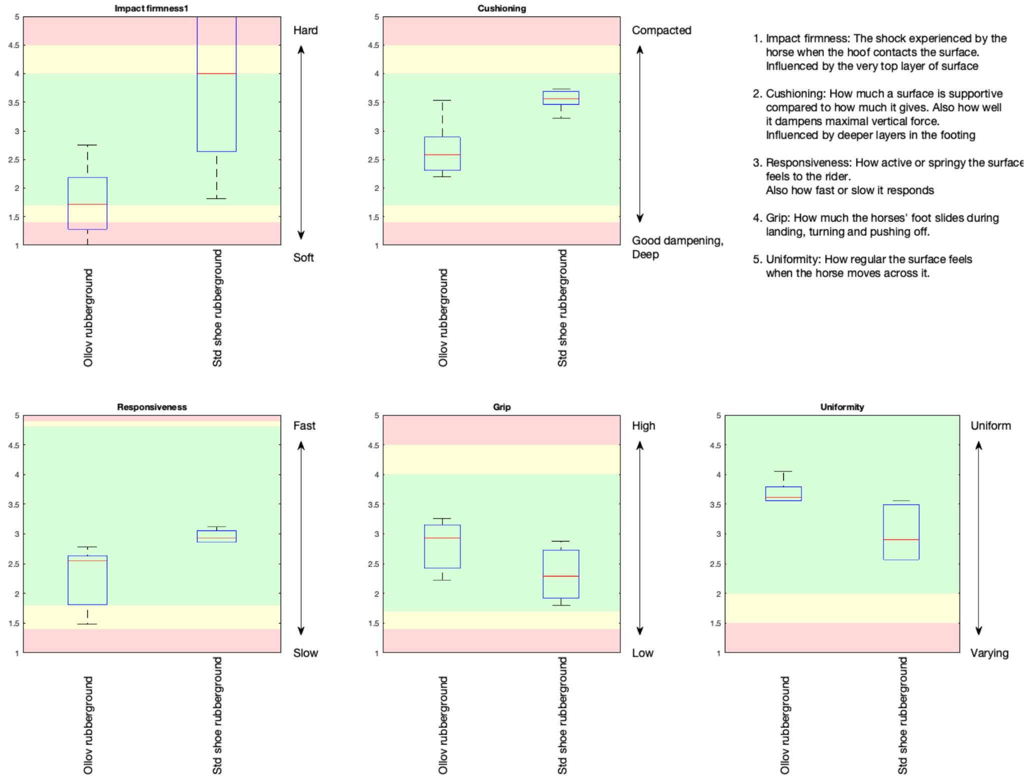
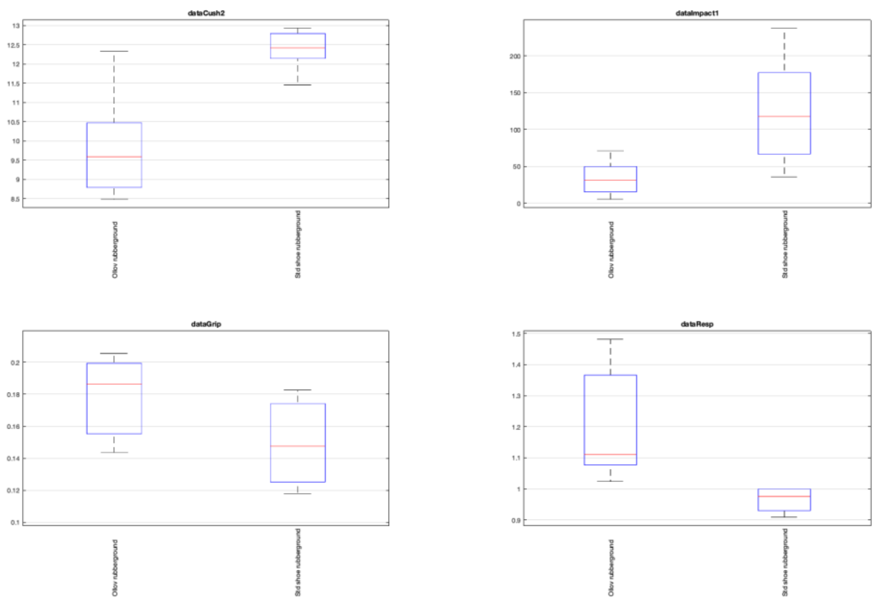
Rubber ground arena:



This ground has a rather hard top layer which is attenuated (73%) with Ollov compared to iron but you also have a better dampening of max forces (23%) with Ollov as seen in a lower cushioning value.

Below a graph with absolute values.



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Standard test method for
In-situ testing of the functional properties of equine arena surfaces

Date of approval: Revision number:

1. Scope

1.1 This test method covers the specification for the measurement of the functional properties of equine arena surfaces, but does not identify a specific device to be used.
1.2 This test method specifies test procedures that are appropriate for field testing of equine arena surfaces.
1.3 This test method defines the functional properties of equine arena surfaces.
1.4 This test method does not specify safety criteria. The extent to which functional properties contribute to individual injury risk is not known.
1.5 Where appropriate values are stated in SI units.

2. Definitions

2.1 The functional properties of arena surfaces are defined as follows[1]:

2.1.1 *Cushioning* - How much a surface is supportive compared to how much it gives when riding on it.
2.1.2 *Impact Firmness* - The shock experienced by the horse and rider when the hoof contacts the surface.
2.1.3 *Responsiveness* - How active or springy the surface feels to the rider.
2.1.4 *Grip* - How much the horses' foot slides during landing, turning and pushing off.
2.1.5 *Uniformity* - How regular the surface feels when the horse moves across it.
2.1.6 *Consistency* - How much the surface changes with time and use.

2.2 The features of an arena are defined as follows:
2.2.1 *Corner* – Identifiable area that is being used by horses to turn from a long to a short side or vice-versa.
2.2.2 *Quarter line* – A line located at either ¼ or ¾ width of the arena parallel to the long side.
2.2.3 *Track* – A regularly used area of the arena that is usually 1-1.5m away from and parallel to the perimeter of the arena.

3. Equipment Specification

3.1 Field testing of equine arena surfaces in-situ must include the following; measurement of the surface cushion moisture content, temperature and depth, dust analysis and measurement of the functional properties of the arena.

3.2 The requirements of the equipment design for testing the functional properties of equine arena surfaces are listed in Table 1. Meaningful between surface comparisons of functional properties are essential.

Table 1: Equipment design requirements

Design Requirement	Current range measured in horses
Quantification of vertical force reduction.	7-14 kN [2,3]
Quantification of vertical impact acceleration	0-350 g [4,5]
Quantification of surface frequency response	time of propulsive phase ≈ 0.1 s [6]
Quantification of horizontal sliding/shear resistance	20-120 mm [7,8]

3.3 The design of equipment (Orono Biomechanical Surface Tester (OBST)) and instrumentation currently used to measure the functional properties of equine arena surfaces in-situ is summarized below. Further information about the OBST can be found at the designer's website[9]. The tester is a two-axis gravity driven impact type of apparatus, which drops a hoof shaped projectile (with size 2 steel shoe) at an angle to the soil surface with a landing speed of approximately 3.8 m/s. The device is supported by a frame that is mounted to a vehicle of sufficient weight to secure it to the ground during testing. In principle, the two non-orthogonal axes of motion drive the hoof into the ground, which produces a simultaneous downward motion and a forward slide of the shoe. This mimics the motion of the forelimb of a horse during the early loading phase. Force is generated by accelerating a 33 kg mass down a long set of rails that are angled at 12 degrees from a 840 mm vertical height. A second set of shorter linear bearings that are vertically aligned accommodate a pre-loaded spring and damper system to which the hoof is attached. This moves down as a part of the mass attached to the slide and when the hoof contacts the ground the second preloaded axis

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is compressed and the difference in angle between the angled rails and vertically aligned bearings forces the hoof to slide forward. Load from the spring-mass-damper system is recorded directly above the hoof using a dynamic load cell (a). Acceleration is recorded from a tri-axial accelerometer attached to a stiff mass above the hoof (b). Deformation and recovery response is measured from a linear potentiometer that is attached to the upper and lower aspects of the linear bearing arrangement (c). Landing speed is measured using a string potentiometer attached to the falling mass of the system (d).

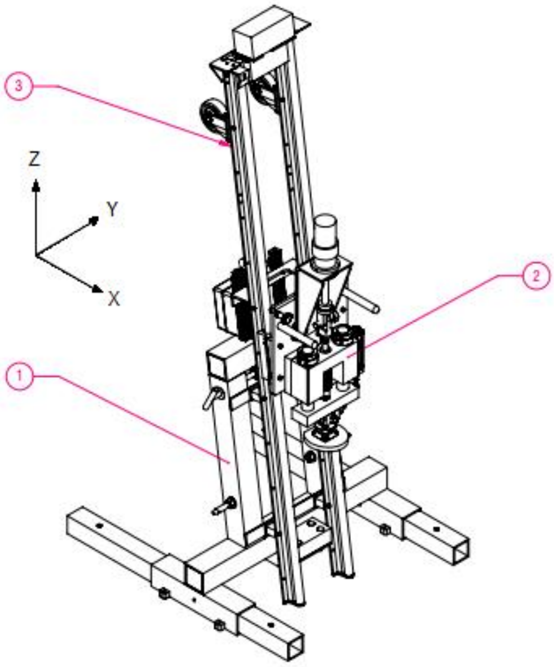

Figure 1: Assembly drawing and photograph of the OBST. 1) Attachment/support frame, 2) Secondary preloaded slide and part of the falling mass, 3) Primary slide guide rails.

3.4 Instrumentation used with the OBST to measure the functional properties of equine arena surfaces is listed in Table 2. Signals from the OBST instrumentation are collected at 5000 Hz synchronously with a 16 bit A/D converter and a digital I/O interface. A user guide for the OBST can be found in Supplemental Information (see Certification Procedure).

Table 2: OBST Instrumentation

Sensor	Specification
Tri-axial load cell (Kistler 9347C)	Fz range ± 30 kN Fn (z) 10 kHz Fy/Fx range ± 5 kN Fn (x/y) 3.6 kHz
Tri-axial accelerometer (Kistler 8793A)	Range ± 500g Frequency response 2.5-10,000 Hz
Linear potentiometer (Novatechnik LWH 75)	Linearity ± 0.05% Repeatability 0.01 mm Operating Speed (max) 10 m/s
String potentiometer (Celesco PT5A-100-N34-DN-500-M6)	Accuracy ±0.25% f.s. Repeatability ±0.02% f.s. Cable velocity (max) 7.6 m/s

3.5 A time domain reflectometry (TDR) soil moisture meter with two 7.5 cm rods is required to obtain in-situ moisture measurement from surfaces that do not contain wax, other moisture replacement products or rubber particles. For all surfaces that a TDR cannot be used approx 125 x 150 mm sealable plastic bags and a sealable container are required.

3.6 For surfaces that contain wax a temperature probe is required to obtain temperature measurements from the surface.

3.7 Needle probe and narrow hand trowel to measure surface cushion depth and inspect sub-surface (where necessary).

3.8 MiniRAE 3000 and 1 litre cover bell to measure Total Volatile Organic Compounds (TVOC).

4. Procedure

4.1 Record the size of the arena plus any notable features (e.g. entrance, equipment store, vehicle access point) on the arena map

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and establish a 0,0 location to the left of the short side (see Appendix A1). Record the maintenance/preparation that has been performed (including moisture management) prior to testing.

4.2 Install 1 litre cover bell at an appropriate location in the arena.

4.3 Inspect and assess the installation plans/ sub-base construction of the arena(s). If necessary, use the hand trowel to remove the surface to the depth of the sub-base in a corner of the arena to verify sub-base construction.

4.4 Determine the number of locations to be tested.
4.4.1 For all sizes up to 20 x 60 m a minimum of 9 locations should be tested (3 corners, 3 tracks and 3 quarter lines). The locations should be chosen based on visual examination of use, arena features and should include measurements that represent the whole area.
4.4.2 For larger size arenas measurements should be taken based on a 15 x 15 m grid.

4.5 For each of the locations identified collect measurements from the mechanical equipment (to obtain functional properties) that represent 1) a newly prepared surface, 2) a partly compacted surface and 3) a fully compacted surface. For the OBST this is performed using 3 consecutive drops on the same location. Record the location (grid reference) and drop number or amount of compaction.

4.6 Collect moisture content measurements as specified below.
4.6.1 For surfaces that do not contain wax, other products that are used to substitute moisture or rubber particles the TDR may be used. For each of the locations identified for mechanical testing take an average of 3 readings from the TDR and record the location (grid reference) and average moisture measurement or include the moisture measurement in the functional properties file metadata.

4.6.2 For surfaces that do contain wax, other products that are used to substitute moisture or rubber particles, 100 gram samples should be collected from each location. Place each sample in a sealed bag and clearly identify the grid reference on the bag. Put all of the samples in a sealable container, label with arena identifiers and date and seal the container. Moisture content from each location must be determined post *in-situ* testing using the procedure described in Appendix B1: Moisture content of equestrian arena surfaces.

4.7 For surfaces that contain wax the temperature probe should be used. For each of the locations identified for mechanical testing take an average of 3 readings from the probe and record the location (grid reference) and average temperature measurement or include the temperature measurement in the functional properties file metadata.

4.8 For each of the locations identified for mechanical testing take a surface depth measurement with the needle probe. Insert the probe into the surface to the depth of the membrane, sub-base or hard pan and record the depth of surface.

4.9 After 1 hour from installation, measure the TVOC level inside the cover bell using the MiniRAE3000 and record. If the measured level is greater than 10.00 µg/m^3 + 20%, then collect a 50 cm x 50 cm x depth sample of the surface. This sample must be sent immediately to a specified laboratory for Level 1 dust analysis testing (as specified in Appendix B16).

4.9 Inspect and assess maintenance protocols as specified below.
4.9.1 For existing arenas view and verify the maintenance log including weather monitoring (for outdoor arenas) with arena maintenance staff. Discuss and agree maintenance protocols for the next certification period.
4.9.2 For new arenas discuss and agree the maintenance protocols (including moisture management and weather monitoring) to be used for the first certification period.
4.9.3 For temporary arenas discuss and agree the maintenance/preparation protocols (including moisture management) to be used for the duration of the event.
4.9.4 When testing arenas immediately before a competition raw results/on site analysis should be performed. Should concerns be raised when comparing to normative data (i.e. functional properties that are in the red zone) additional testing should be performed in consultation with the surface providers/footing experts/maintenance personnel following corrective maintenance/preparation.

5. Calculations

5.1 Calculation of the functional properties of arena surfaces are described below. For the OBST, calculations may be performed using

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OBST Matlab scripts[10], using Appendix D1 or using the information and calculations described in this section (Section 5).

5.1.1 To remove unwanted signal noise, appropriate filtering may be applied to the sampled signals. This must be specified in the report. For the OBST the raw signals are filtered as described in Table 3.

Table 3: Filters used with OBST data

Sensor	Filter
Tri-axial load cell	4^{th} order bi-directional Butterworth with 400 Hz cut off[10].
Tri-axial accelerometer	4^{th} order bi-directional Butterworth with 400 Hz cut off[10].
Linear potentiometer or equivalent	4^{th} order bi-directional Butterworth with 100 Hz cut off[11].
String potentiometer or equivalent	4^{th} order bi-directional Butterworth with 100 Hz cut off[11].

5.1.2 Raw signals must be converted from voltages into SI units for each sensor using current calibration information.

5.1.3 An event to define initial contact with the surface is required. For the OBST a threshold of 50 N from the vertical component of the tri-axial load cell is used to define initial contact.

5.1.4 Hoof landing speed of the equipment is required. For the OBST this is obtained by calculating the first derivative of the string potentiometer signal, from which vertical and horizontal components are determined.

5.1.5 Quantification of the functional properties of arena surfaces is described from the OBST below. Examples of these calculations are shown in Figure 2. Equivalent measurements must be verified against OBST measurements if using other equipment.

Cushioning (kN) – is quantified as peak vertical force recorded by the tri-axial load cell.

Impact firmness (g) – is quantified as peak vertical deceleration from the tri-axial accelerometer.

Responsiveness (ratio) – is quantified as time between peak spring compression velocity and maximum spring compression/ the time between maximum spring compression and peak spring recoil velocity.

Grip (mm) – is quantified as the fore-aft horizontal slide distance of the hoof. This is calculated using the horizontal component of the tri-axial load cell and the horizontal speed of the string potentiometer at initial contact.

a) Divide the fore-aft load signal by the sliding mass to obtain the fore-aft acceleration measured by the load cell.

b) Calculate the indefinite integral of the acceleration from initial impact using a constant of zero to obtain fore-aft horizontal velocity.

c) Calculate the indefinite integral of the fore-aft velocity from initial impact using the fore-aft component of landing speed from the string potentiometer as a constant to obtain fore-aft displacement.

d) Determine the hoof slide (grip) from the fore-aft displacement signal from initial impact to peak vertical force (i.e. during the loading phase).

Uniformity - Calculate the coefficient of variability for each functional property separately. Calculate the ensemble mean of the coefficients.

5.2 Normative values for each functional property (to a 1-5 scale) are determined from functional property metrics, based on the work of Hernlund (2016)[11]. Conversions and relevant traffic light ranges are described in Table 4.

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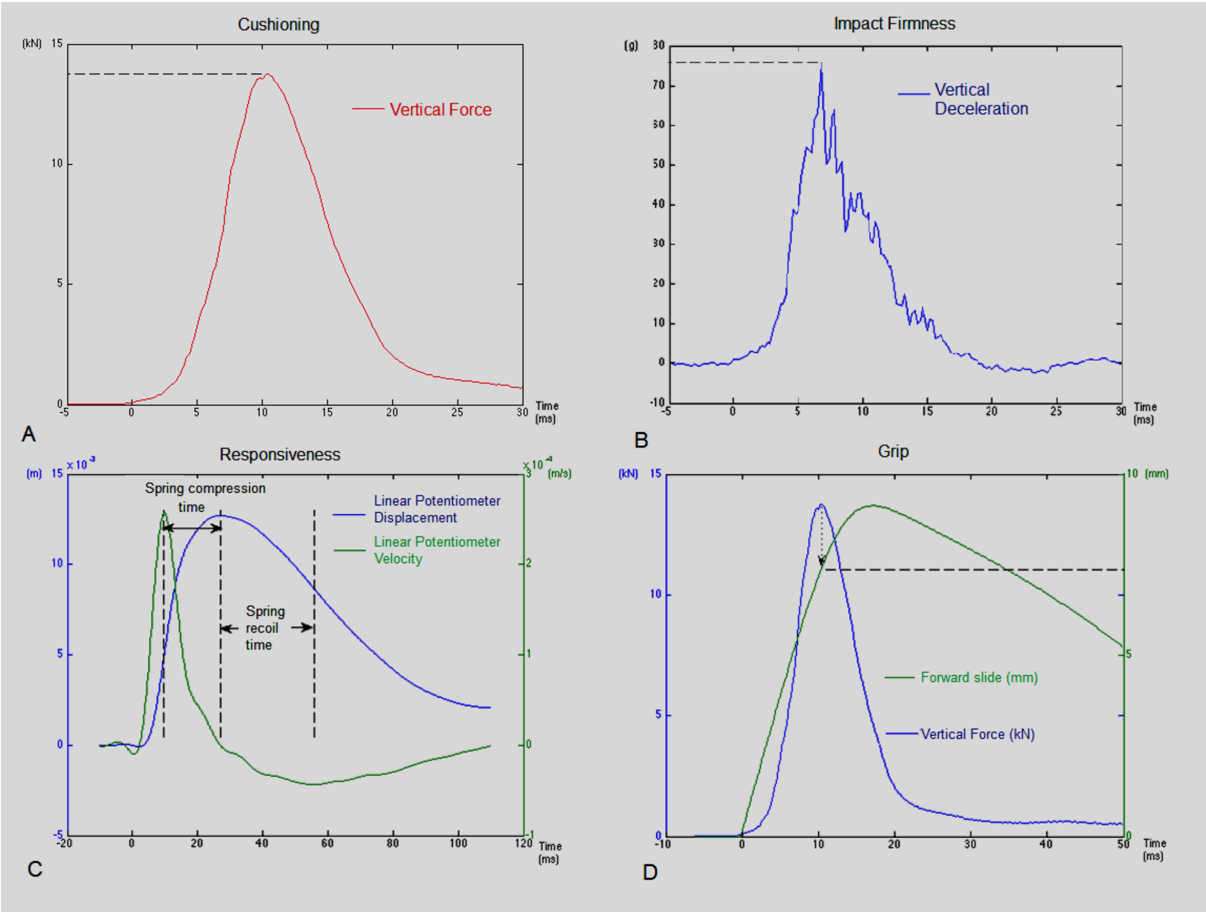

Figure 2: Graphical descriptions of the functional properties calculated using the OBST. A) Cushioning, B) Impact Firmness, C) Responsiveness, D) Grip.

Table 4: Normative OBST Metrics

Functional Property	Conversion	Green Range	Amber Range	Red Range
Cushioning (kN)	((Cushioning-8)/(16/5))+1	1.7 to 4	Lower:1.4 to 1.7 Upper:4.0 to 4.5	Lower: 1 to 1.4 Upper: 4.5 to 5
Impact firmness (g)	((IFirmness-15)/(250/4))+1	2 to 4	Lower: 1.5 to 2 Upper: 4 to 4.5	Lower: 1 to 1.5 Upper: 4.5 to 5
Responsiveness	(5-(Response+0.1)/(1.1/4))+1	1.8 to 4.8	Lower:1.4 to 1.8 Upper:4.8 to 4.9	Lower: 1 to 1.4 Upper: 4.9 to 5
Grip (m)	(5-(Grip+0.002)/(0.01/4))+1	2 to 4	Lower: 1.5 to 2 Upper: 4 to 4.5	Lower: 1 to 1.5 Upper: 4.5 to 5
Uniformity	(5-(Uniformity+0.2)/(1/4)+1	2 to 4.8	Lower: 1.5 to 2 Upper:4.8 to 4.9	Lower:1 to 1.5 Upper: 4.9 to 5

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6. Reporting of results

FEI standard report format for *in-situ* testing can be found in Appendix D1. All reports should contain the following information. Report the following information:

6.1 Report date and test date.

6.2 Name of laboratory, company, or individual issuing the report.

6.3 The geographical location of the arena(s) to be tested.

6.4 The number and type of arenas that were tested.

6.5 Level 1 and Level 2 materials testing document references. A description of the top and base layers, drainage system, age and usage of the main arena surface. A description of the warm up arena/ additional arena surface(s).

6.6 A description of the preparation/ maintenance carried out prior to testing.

6.7 Confirmation that the maintenance log is complete and the maintenance regimen is being followed as agreed.

6.8 A qualitative description of any other conditions that may have influenced the results (including ambient temperature, weather conditions, construction information etc.).

6.9 The number and type of test locations in each arena.

6.10 The moisture content and variation across the arena.

6.11 Where applicable (for waxed surfaces) the surface temperature and variation across the arena.

6.12 The depth of the top surface and variation across the arena.

6.13 Metrics from the calculated functional properties.

6.14 Analysis of the findings compared to normative data.

6.15 Assessment of the maintenance log and/or preparation used for testing.

6.16 Comparison of the installation against submitted plans (if required) and information about the sub-base.

6.17 Agreed remedial work, maintenance and/or required alterations in preparation (if needed). This should be in consultation with footing experts/on-site maintenance team and laboratories analysing material samples.

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