The effects of dressage competitions on the mechanical properties of a synthetic equestrian arena surface

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Declaration

I hereby declare that the work within this dissertation is my own and is not the collaboration of others. I am happy for the work to be available for reference within the Myerscough College library.

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Abstract

Properties of equestrian surfaces such as hardness, traction and resistance to penetration may change during competition. A surface itself has a direct impact upon an athlete since it is the primary point of contact, therefore any changes which occur could affect performance or the possibility of injury. At present management regimes which are aimed at reducing such risks are based upon anecdotal evidence from site managers and surface construction companies. The aim of the present study was to validate a suite of mechanical tests on sand, fibre, rubber and wax equestrian surface, which were then used to quantify the effects of a preliminary, unaffiliated dressage competition on the hardness, traction and resistance to penetration of the surface. In addition laboratory analysis was used to determine surface components and the effects of temperature on the surface. The mechanical properties that were measured were hardness, using a Clegg Impact tester, traction, using a torque wrench and penetrability, using a penetrometer. Each piece of equipment was tested on a prepared, synthetic equestrian surface at Myerscough International Arena, in order to determine the method of use which produced results with least variability. The results of this work suggested that the 2.25kg Clegg hammer, the torque wrench using a horse shoe plate, under a weight of 30kg, and the Longchamp penetrometer, should be used. It was also found that five repetitions should be made in a single position with each piece of equipment. The equipment was used to test a 20m x 40m dressage arena, before and after six preliminary, unaffiliated dressage competitions, held between January and June 2009. Thirty two positions were tested within the arena, which were split into two sets of 16. The first set of 16 were positioned 7.5m apart around the outside (track) area, and the second set of 16 were randomly positioned in the central area using a stratified random sampling method. In addition, temperature data was recorded at each of the competitions. The results showed that the hardness of the surface increased significantly ($P<0.05$) after a preliminary, unaffiliated dressage competition. The changes in the traction of the surface varied with each competition, all changes were found to be significant ($P<0.05$). The results regarding the penetrability of the surface were affected by the presence of the fibres in the surface, and therefore were deemed unreliable in this instance. There were significant changes to the surface over the period of six months, hardness decreased from 80±0.9G to 62±0.8G ($P<0.001$), traction decreased from 21.5±0.1Nm to 16.9±0.1Nm ($P<0.001$) and total penetration depth increased from 1.9±0.03cm to 3.6±0.06cm ($P<0.001$). There were significant differences found between the mechanical properties of the track and the central areas ($P<0.05$). The findings show that the mechanical properties of the surface changed significantly over a dressage competition. Short term changes could leave late competitors working on a different surface to early competitors, thus the running order of an event could affect the results. This highlights a need for further examination of the interrelationship between performance and surface variability. Significant long term changes were evident in hardness, traction and penetration, highlighting the need for a management protocol informed by surface testing in order to provide a surface with consistent properties.

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1.0 Introduction

In 2004 the Federation Equestre Internationale (FEI) published a paper detailing the injuries that four jumping horses sustained at the Athens 2004 Olympic Games. All of the injuries were described as ‘severe tendon injuries’ which occurred ‘while in the arena.’ Suggestions were made that it could have been the footing of the arena surface that had caused the injuries. This suggestion gave rise to questions about the competition surface and therefore highlighted a need for research into the impact of surfaces and how similar situations can be avoided in the future (FEI, 2004).

In the past two decades, training surfaces in the racing industry and the equine industry as a whole have evolved. Research into equestrian surfaces has increased recently, and the research which is available does highlight the limitations of equestrian surfaces which have driven the evolution. A large proportion of the evidence available to the industry is still anecdotal though. The key theme which is consistent throughout the research into equestrian surfaces is that of the forces incurred by horses and the close link those forces have to injury risks. Moyer *et al.* (1991) reported that incidences of dorsal-metacarpal disease in Thoroughbred racehorses were significantly higher when trained on dirt surfaces compared to wood fibre surfaces, suggesting that even when large-scale manufacture of equestrian surfaces was in its early stages, the potential for injury was already a concern. Since the publication of the work by Moyer *et al.* (1991) equestrian surfaces have gone through a series of amendments from pure crushed sand surfaces, to the addition of rubber and fibre. Similar progression of surfaces has been noted in those used for human sports such as football and golf. Spring and Baker (2006) suggested that the inclusion of polypropylene and polyurethane fibres reduced surface displacement in football pitches. When applied to an equestrian surface this is an important factor in terms of the amount of slip which may be experienced by an athlete, and therefore the likelihood of an injury occurring (McClinchey *et al.,* 2004). The inclusion of crumb rubber within a surface has been proven by Groenvelt and Grunthal (1998) to significantly reduce the surface hardness of golf courses. Once again, when related to an equestrian surface, the hardness significantly affects the likelihood of injury (Baker and Cannaway, 1993). Most recently equestrian surfaces have been produced which have been treated with a palm oil-based wax. Research into the use of these waxed surfaces by Chateau *et al.* (2009a) in trotting races has shown that peak forces on the limbs are decreased on when compared to pure sand surfaces. Similar results were reported by Crevier-Denoix *et al.* (2009). In addition Robin *et al.* (2009) noted that stride length was significantly reduced on the waxed surfaces compared to crushed sand surface, suggesting that specific surfaces affected the movement of the test subjects.

Despite the recent advances in determination of the effects of a surface on an equine athlete detailed, there is no evidence from equestrian scientific research which suggests the effect of the athlete upon the mechanical properties of the surface. There are equestrian sports which are open to every level of horse and rider combination, in particular, dressage is a discipline with competitions with a wide range of levels from preliminary walk and trot tests upwards. Competitions are run so that every horse and rider combination has to perform the same “test,” or sequence of movements and paces, within a set area. This means that measuring any changes in the mechanical properties of a particular surface is achievable throughout dressage competitions, when compared to measuring changes to the mechanical properties of a racetrack, for example, which requires equipment to be carried a large distance by car (Peterson *et al.,* 2008), and is logistically more of a problem. Measurements such as the hardness, traction and resistance to penetration may be taken.

1.1 Introduction to Sports Surfaces and the Impact on the Athlete

A sports surface has a direct physical impact on an athlete since it is the primary point of contact at any time (Hsu and Su, 2007). Witana *et al.* (2009) stated that the interaction of the plane of an athlete’s foot and the load bearing properties of the surface affect the movement of the athlete and displacement of the surface beneath the athlete. This interaction has been found to affect the likelihood of an athlete sustaining an injury. In equine sports, it is vitally important that a surface is capable of bearing excessive loads, with only small amounts of displacement, whilst still being malleable enough to reduce concussive forces on the limbs through slip (McClinchey *et al.,* 2004). Witte *et al.* (2006) suggested that in racing, when a horse is it maximal speed, the peak vertical force exerted is approximately 2x the total body weight, In dressage the horse will not reach this maximal speed, however the surface must still be capable of bearing a significant vertical load. In addition, the surface must provide enough traction to prevent the horse from slipping or falling, but equally, not so much traction that there is a resulting concussive effect on the limbs.

Murray *et al.* (2010) and Riggs (2010) have both stated that equestrian surfaces must be consistent in order to reduce the likelihood of an injury occurring. Conversely, in long term training programmes, alteration of mechanical environmental factors such as the training surface, allows bone growth and adaptation. This enables the limbs to bear required loads throughout training and competition and therefore reduces the likelihood of an injury occurring (Price *et al.,* 1995). In lower level competitions ground conditions and footing may be inappropriate, simply due to a lack of sufficient resources, however this, combined with amateur riders is a risk factor for injury. Dyson (2002, page 146) stated that “Any sudden change of surface integrity will predispose to lameness.” At present there has not been any research to suggest that grass arenas affect the risk of injury differently in comparison to artificial arenas (Singer *et al.,* 2008), that is not to say though that there is no risk of injury on any surface. In the racing industry, tracks and surfaces vary between training yards and different track surfaces may be a risk factor for injury (Davies and Merritt, 2004). Moyer *et al.* (1991) studied the variance in the incidence of dorsal metacarpal disease in Thoroughbred racehorses on two training surfaces and the incidence of disease was found to be significantly higher in horses trained on a dirt surface when compared to a woodchip surface. Cheney *et al.* (1973) suggested that incidences of lameness could be affected by variables such as moisture content, dry density and depth of layers of the training surface.

Future research must address the gaps in the current literature. At the very least it is important to assess the effect the surface has on the acceleration, stopping and turning ability of the athlete (Dixon *et al.,* 2006), since it is these factors which will directly affect loading of the limbs, performance and the likelihood of an injury. Ideally, an equestrian surface should therefore be fully tested prior to use and then prepared and maintained to a specific standard. Standards should be set in order to prevent injury to the horse, to maintain levels of equine performance, to prevent damage to the surface and to maintain longevity of the surface. At present, no such standard exists, despite there being more than 300 specifications for the production and maintenance of human sport surfaces (BSI, 2008). This lack of standardisation is mainly due to lack of funding for the research, and also perhaps some lack of consideration by governing bodies, in determining these standards, and then to maintain standards within the equine industry.

1.2 Regulation of Sports Surfaces

Sport surfaces used by human athletes at higher level competitions are standardised and tested by the British Standards Institution, and this has been the case for over two decades (Brown, 1987). The sports council also provides specifications for sports surfaces and it recommends that these are adhered to (Brown, 1982). These standards were set due to the ever-evolving research and legislation in Europe particularly into areas such as sports performance, player safety and durability of the surface. Legislation also details recommendations for the design and maintenance of those human sports surfaces. Improperly researched, installed or maintained surfaces may lead to shortening of the life expectancy of the surface, changes in surface characteristics and the financial implications associated with these changes. Radin *et al.* (1973) suggested that changes in the surface characteristics may also have a knock-on effect on the athlete leading to excessive loading of the limbs and an increased likelihood of injury occurring.

The British Equestrian Federation is the governing body for equestrian sports in the United Kingdom and supports research within the equine industry (BEF, 2008). The organisation does not, however, provide any recommendations regarding the construction, use, preparation or maintenance of artificial or natural equine sports surfaces. The British Standards Institution (BSI) also has no published standards for the construction, preparation or maintenance of equestrian surfaces (BSI, 2008). The lack of standards throughout the industry though, is closely linked with the lack of scientific research, despite the availability of a significant amount of anecdotal evidence to the industry. At present there are limited in field methods available for testing equestrian surfaces, and those that are available are often related to the effects of the surface on the horse. Chateau *et al.* (2009a) for example reported that trotting horses working on waxed surfaces experienced significantly lower ground reaction forces than those worked on a crushed sand surface. Conversely, the physical properties of the surface itself, which can then be linked to how the surface affects the horse, have not been explored. In addition, the majority of research is being undertaken within the racing sector of the equine industry, since this is the area in which funding is more readily available. The equine industry though is defined by its disciplines, with each one inducing very different effects on the surface and the horse, therefore it is important to question whether research carried out in one discipline can be immediately transferred and applied to another. This lack of consistency in areas of research and standards, throughout the industry is a concern both in terms of performance and injury risk. Until a regulatory standard can be achieved, the situation is unlikely to change, and as the equine industry grows, and there are more owners who ride and compete for leisure purposes, and as standards of competition and training become higher, the need for research has become even more apparent.

1.3 Artificial Sports Surfaces

Peterson *et al.,* (2008) suggests that the peak deceleration of a hoof upon impact can be directly related to surface structure and soil strength. The newer generation of artificial sports surfaces are being designed to mimic the root structure and stability of natural turf and reduce the likelihood of injuries in a number of sports, including equestrian sports and football (Richards, 1994). The main constituent of these surfaces is polypropylene fibres which are then filled in with sand and rubber. Such surfaces have been found to be favourable by football players; in particular, a survey by Zanetti *et al.* (2009) suggested that players favour such surfaces for all-weather use. The compliance to loading of a surface is also known to be a significant factor influencing the loading of the limbs (McMahon and Greene, 1979). These new surfaces provide a different set of stiffness, friction and elastic properties when compared to natural turf playing surfaces, and, in human athletes, it is these mechanical properties which can affect limb kinematics and the likelihood of injury (Hardin *et al.,* 2004). Barrett *et al.,* (1997) suggested that the stiffness of a surface affected the likelihood of an injury. The paper stated that fewer injuries were likely to occur on softer surfaces with more compliance, as opposed to stiffer, harder surfaces. Ford *et al.,* (2006) suggest that the levels of friction experienced by footballers on are significantly lower on synthetic turf, as opposed to natural turf, thus the levels of injury associated with excessive friction are reduced on artificial turf. The paper suggests that this occurs due to the interaction of the football boot cleats with the surface, on a natural turf surface greater friction is experienced as the boot cleats get dug into the grass. The elasticity of a surface may be altered by the surface components and this has been shown to affect kinematic parameters such as stride length (Buchner *et al.,* 1994). Ford *et al.* (2006) determined that there was an association between in-shoe loading patterns experienced by runners on synthetic and natural turf surfaces. The same study suggested that the distribution of a load on the limbs is directly affected by the type of surface used in running and this can influence the type of an injury of an athlete is likely to incur. Tessutti *et al.* (2010) reported that in human athletes running on a harder, more rigid surface such as asphalt increases the peak loading of the limbs and therefore increases the likelihood of an injury occurring. The same study suggested that conversely, running on surfaces such as grass encourages greater contact time between the surface and the foot, and also a greater contact area of the foot on the surface. This leads to a decrease in the peak loading of the foot on softer surfaces, and thus decreases the chance of an injury occurring. Kim and Voloshin (1992) had similar results which suggested that running on asphalt increased the amplitude of shockwaves by 25 percent, compared to a grass surface.

The equine limb differs significantly from that of a human athlete and therefore surfaces are likely to affect limb kinematics in different ways. The most noticeable difference is the length of the muscle fibres. McGuigan and Wilson

(2003) state that in equines have relatively short muscle fibres and long tendons, compared to smaller mammals which have much longer muscle fibres. The short muscle fibres of the equine limbs reduce the ability of the horse to alter limb stiffness in order to comply with changes in a surface (Ferris and Farley, 1997). Changes in kinematics due to changes within a surface may still occur though and can be measured *in vivo*.

The kinematics of a moving horse can be determined by studying joint angles throughout a single stride, and can subsequently be related to ground reaction forces (Hodson *et al.* 2001) and joint powers (Clayton *et al.* 2001). Such information is gathered using biomechanical gait analysis systems. Biomechanical analysis of the athlete involves three-dimensional, computer-aided tracking of movements and forces. This, combined with mathematical programming means that the dynamics of movement can be assessed, including stride lengths and joint angles (DeLuzio *et al.* 1991). The basic method for performing a gait analysis study involves gluing markers to specific locations on the athlete and then filming that athlete. Films are then imported into a gait analysis computer programme and successive images are used to measure the aspects of movement which are of interest (Barrey, 1999). In human research this technology has been compared to basic visual assessments. Results have shown that simple visual assessments are not enough with researchers consistently underestimating joint angles by as much as 19º (Krosshaug *et al.* 2005). One of the biggest limitations of the gait analysis systems is the effect of skin displacement on the positions of markers during the final analysis. This skin displacement gives an inaccurate picture of the relative underlying bone structures and movements. It is vital that statistical analysis takes displacement into account and corrections are made (van Weeren *et al.* 1992). In addition to this, research in dogs has shown that breed differences and differences in gait symmetry have an impact on results and hence may affect interpretation and comparisons. It has been suggested that in order for gait analysis to be used effectively a dog must be assessed at a constant velocity in a symmetrical gait i.e. trot (Gillette and Angel, 2008). If this was also true of horses then assessments in canter and/or jumping assessments may be invalidated. Despite this, gait analysis is widely used and exploited in commercial and clinical use.

In the equine industry, tracks and surfaces vary between different training yards (Davies and Merritt, 2004). Surfaces which are available to both industry professionals and the layperson offer a wide range of constituents from wood chip (Barrey *et al.,* 1991) to carpet. Each of the surfaces which are available to the industry could have a significant effect on the kinematics of the horse, and the likelihood of an injury occurring. Synthetic surfaces are a popular choice, and there are generally four main constituents which may be mixed in various ratios to produce such a surface. The constituents are sand, fibre and rubber, with the option to also mix the surface with wax, all of which may individually influence the structure, hardness, stability of the surface beneath a moving horse.

1.3.1 Sand

The sand content of a surface can be characterised in terms of its particle size, distribution of particles and uniformity of particles. These factors affect porosity, drainage rates and some physical properties such as shear strength, of the underlying soil and the surface itself (Zhang and Baker, 1999). In addition, the shape of sand particles has a direct effect on the displacement or movement of a surface. Cruse *et al.* (1980) stated that rounded particles are more likely to move when subjected to compaction during play when compared to particles which are angular in shape. Further to this early research, Yi *et al.,* (2001) suggested that angular sands have low bulk densities before compaction due to a large number of pores (air-filled spaces) between the angular grains (Grujicic *et al.,* 2006). When a surface becomes compacted under an imposed stress, such as a horse moving across it, the air-filled pores between sand particles decrease in size and therefore compaction of the surface occurs (Meade, 1966; Whalley *et al.,* 1995). In human sports surfaces such as winter games pitches with sand-based rootzones, which are subjected to heavy use, amendments such as crumb rubber have been introduced. Baker *et al.* (2001) suggested that these amendments can be used to reduce this compaction, and therefore also reduce hardness. Similarly, equestrian surfaces are subjected to heavy stresses during dressage competitions, with horses repeatedly moving across the same areas, which would increase the likelihood of compaction, and thus alter the hardness, traction and resistance to penetration. As a result of this, equestrian sand surfaces are almost always amended with other materials.

1.3.2 Fibre

The stability of an equestrian surface will be affected by the number of horses using the surface, which in the case of a dressage competition can be over 100 horses in a single event. Beard and Sifers (1993) commented that a surface which is used frequently and at a high intensity such as in dressage is susceptible to high levels of wear, tear and compaction, therefore it would be vital in this case to use an amendment to maintain surface stability . Richards (1994) discussed the use of interlocking pieces of mesh to stabilise a turf surface used in golf courses, both on the top and in the layers below. The study found that including mesh pieces into the surface significantly reduced the amount of compaction due to an increase in the number of air-filled pores between the soil particles, thus giving a higher quality of playing surface. More recently, polypropylene fibres have been developed, in straight and crimped forms, which are designed to interlock with a sand surface. Gibbs (2002) found that turf surfaces with sand-based rootzones, which have been treated with the fibres retain greater ground coverage compared to untreated sands. The results suggest that the fibre improves surface stability and decreases the risk of the surface becoming displaced during use. Spring and Baker (2006) found that the inclusion of polypropylene and polyurethane fibres into a fibresand mix had a similar effect. The same study also stated that the fibre additions significantly reduced hardness and ball rebound in simulated football match conditions, suggesting that the inclusion of fibres could also be associated with reducing injury rates. The studies which have been detailed, suggest that there is a positive effect of amendments on the physical properties of the surfaces used by humans. In particular, since hardness and compaction have been linked to peak loading, concussion and injury, any decrease in these factors would be beneficial. Tessutti *et al.* (2010) reported that the hardness of sports surfaces used for humans can be directly linked to peak loading of the limbs, and therefore the risk of injury. The fibre additions in synthetic equestrian surface may therefore be a positive step forward in reducing the amount of concussion on the limbs, as well as playing a crucial role in maintaining surface stability and reducing displacement.

1.3.3 Rubber

The use of rubber crumb in sand-based rootzones has on occasion been successfully used in surfaces which are subjected to heavy usage (Baker *et al.,* 2001a). With regards to equestrian surfaces this is particularly important, when surfaces may be subjected to use for up to 16 hours a day, with up to 100 horses competing in one competition (these figures were obtained from Myerscough International Arena records, which are discussed further in later chapters). Baker *et al.* (2001a) found that the addition of crumb rubber to winter games pitches decreases the overall hardness due to the elastic properties of the rubber. A similar effect could be beneficial in equestrian surfaces in reducing injury through concussion and also in enhancing certain gait qualities such as stride length (Buchner *et al.,* 1994). It was also found by Rogers *et al.* (1998) that an amended surface did not breakdown at the same rate as a surface without the amendment, thus suggesting that the crumb amendment increased the longevity of the surface. On golf courses, the addition of 10-20% crumb rubber, by weight has been shown to have the same effect of significantly reducing surface hardness (Groenevelt and Grunthal, 1998). A direct comparison of equestrian and human sports pitches would be difficult given the size of the athletes in question; however the inclusion of rubber in a modern equestrian surface is relatively common practice and could be a positive step in reducing the likelihood of an injury occurring through concussion to the limbs.

Synthetic sports and playground surfaces are increasingly found to contain recycled rubber from car tyres. In addition rubber car tyres contain certain metals, which have been shown to leach into the environment in concentrations of up to 2500µg/litre in the case of zinc (Bocca *et al.,* 2009). The leaching of metals such as zinc, from these rubber constituents, can affect water quality and induce toxic affects in organisms (Gualtieri *et al.,* 2005). Groenvelt and Grunthal (1998) found that there were no deleterious effects of using crumb rubber as a surface addition on golf courses, when leachate was tested for metals such as zinc. At present though there are no published guidelines for the laying or disposal of artificial surfaces which give details of environmental issues (Bocca *et al.,* 2009), therefore it is important that further research is undertaken to determine the ideal rubber to use within a surface, which does not cause environmental damage.

1.3.4 Wax

The presence of a binding substance has been shown to significantly alter the physical characteristics of fine grade sand surfaces, and therefore alter the interaction of an athlete with that surface (Pinnington and Dawson, 2001). Simply adding water to a sand surface can increase the hardness by a factor of six, as the water fills the air-filled spaces between sand particles, thus giving a more stable surface which Barrett *et al.* (1998) described as exhibiting similar properties to a synthetic running track. Football pitches are regularly irrigated to prevent the surface drying out leading to wind and water erosion of the underlying soil, and to maintain growth of healthy turf. Anecdotal evidence suggests that older equestrian surfaces which did not contain a binding substance required regular irrigation. It is also important to maintain the recreational and aesthetic appeal of the surface. Regular watering of a surface using water conservation and irrigation systems has been found to be expensive to install, and this discourages sports grounds from investing in such systems despite the benefits to the environment of reducing water usage (Carrow, 2006). An alternative to water treatment of surfaces is to mix the surface constituents with wax, and modern suppliers of modern equestrian surfaces are constructing surfaces using wax in order to minimise water usage in arenas.

Research into waxed equestrian surfaces compared to crushed sand surfaces, for use in trotting races, has had some positive results. Robin *et al.* (2009) validated and tested a dynamometric horseshoe on a waxed and crushed sand surface, and determined that ground reaction forces and therefore peak loading of the limbs was significantly lower on the waxed surface when being used for trotting races. In addition, Chateau *et al.* (2009a) suggested that waxed surfaces had better shock absorbing properties, and therefore decreases the deceleration of the hoof upon impact with the surface. As a result of this, maximal tendon force was reduced on the waxed surface, suggesting that there is a lower likelihood of an injury occurring on a waxed surface, during trotting races (Crevier-Denoix *et al.,* 2009). Stride length was significantly reduced by up to six centimeters on the waxed track compared to crushed sand surface (Robin *et al.,* 2009). When related to trotting races it is possible that this would not affect the outcome of a race, since all horses would be performing on the same track at the same time. In comparison though, competitors in a dressage competition perform one after another, suggesting that if the surface changes between competitors, it may affect on stride characteristics, which may then affect the competitor's test score.

Commercial waxes have melting temperatures which range from approximately 50℃ to over 100℃. Up to this temperature wax undergoes a gradual decrease in solidity and stability (Binks and Rocher, 2009). The wax constituent of the equestrian surfaces contains palm oil, which is known to start to crystallise in temperate climates when temperatures reach lower than 15℃ (Mammat *et al.* 2005), therefore above this temperature the wax may be more semi-solid, and below this temperature the wax is likely to be crystalline. In relation to equestrian surfaces, this means that a surface could have a different set of physical properties such as hardness, traction and resistance to penetration during warmer temperatures as opposed to colder temperatures depending upon the time of year. Wax substances with high oil content are known to have lower melting temperatures than those containing less oil (Choi *et al.,* 2009). A similar issue was explored by Bridge *et al.* (2010) which suggested that the waxes used within American synthetic race tracks had initial peak transitions between 22℃ and 33℃, and final melting points ranging from 67℃ to 84℃. The results from that study indicated that the waxes currently used in the specified surfaces were not stable enough to withstand daily temperature fluctuations, and therefore could affect surface mechanical properties. The study suggested that combining the oil base with a microcrystalline wax and paraffin wax can increase the stability of the blend at increasing temperatures. It is therefore important that the synthetic equestrian surface in this study is tested during different seasons, and at extremes of temperature, to determine if there are any significant effects on the mechanical properties.

1.4 Measurement of Sports Surfaces

Assessment of the physical characteristics of a sports surface is dependent upon the purpose of the surface. Measurable characteristics of playing quality can be generated by trying to mimic player-surface interactions (Chivers and Aldous, 2003). When related to equine interactions with a surface though mimicking the horse is difficult given the sheer size of the athlete in question. In equine sport one of the most important aspects of testing sports surfaces is determination of shock attenuation, as Naunheim *et al.* (2004) described in human athletes, this is very closely linked to the likelihood of injury. There are numerous examples of tests which may be done on surfaces, including the Berlin Artificial Athlete which was designed in 1976 for in-situ testing of human sports surfaces (Hsu and Su, 2007). Suggestions have been made by Nunome *et al.* (2007) when investigating loading and shock attenuation in third generation artificial turf that the Berlin athlete does not reflect the actual loading mechanisms of sports movements. There is therefore a need for higher shock absorbency and higher loading tests to be undertaken. Peterson *et al.* (2008) described a piece of equipment designed to take in-situ measurements on a racetrack in order to aid track maintenance. This equipment was designed to overcome the issue of mimicking the interaction of the hoof and track in a specific equine gait at the point when the hoof contacts the track and the weight is transferred. At this point the vertical loading of the limb is at its peak and therefore the likelihood of concussion is high. When piloting this system it was found that it was possible to detect differences in harrow depth of a surface, hence giving rise for the potential to prepare different tracks to one pre-determined, standard harrow depth to encourage consistency between racecourses. One of the problems with this equipment is that it has to be rigged to a car and therefore logistically could cause problems within a small dressage arena, therefore alternative pieces of equipment need exploration.

1.4.1 Hardness

Shock attenuation is closely linked to how hard a surface is, and hardness can be directly related to the impact of a player on a surface during running and/or falling on, for example, a football pitch as described by Baker and Cannaway, (1993). In addition, the hardness of the surface can be linked to how compacted it becomes under the imposed stress of use. Compaction is directly related to air-filled porosity, that is the greater the number of air-filled pores, the more compaction is likely to occur (Meade, 1966) As already discussed, the shape of the sand particles within equestrian surfaces will affect the likelihood of compaction occurring, the more angular the sand, the more likely that compaction will occur (Gruijicic *et al.,* 2006). This is also likely to affect changes in the hardness of the surface throughout competition. The hardness may also be attenuated by the fibre and rubber content of the surface.

In order to measure the hardness of a surface, a Clegg impact tester may be used (Clegg, 1976). This equipment was described by Richards (1994) and consists of a hollow tube, a 50mm diameter hammer which is fitted with an accelerometer and a digital display meter. The hammer is dropped from a pre-defined height and the meter displays the maximum deceleration upon impact with the surface. The height from which the hammer is dropped varies between studies, for example, Spring and Baker (2006) used a 0.5kg Clegg Hammer from a drop height of 0.55m to test professional football pitches, whereas Baker and Firth (2002) used the same weight of Clegg hammer but from a height of 0.3m to test greyhound racing track. It is possible that these studies chose the specific drop heights to suit the surface which was being tested, and therefore a specific height suitable for testing a synthetic equestrian surface should be determined prior to the onset of testing on that surface.

Clegg hammers are available in different weights, including 0.5kg and 2.25kg. In cricket pitch testing, it has been found that the height and weight variables of the impact tester affect results. It was suggested by Baker *et al.* (2001b) that either original height should be increased, or the weight of the hammer should be increased in order to improve correlation of results. A subsequent study by

Baker *et al.* (2007) suggested that the 2.25kg Clegg hammer had greater kinetic energy before impact compared to the 0.5kg hammer, thus giving a more accurate impression of the deeper aspects of the surface, below the topmost layer. The same study suggested that the 2.25kg hammer was less variable than the 0.5kg Clegg hammer since the 2.25 kg hammer has higher impact energy than the 0.5kg hammer. This suggests that the 2.25kg hammer is less likely to rebound on the softer top layer of a surface. When related to a synthetic equestrian surface, a similar effect may be seen. In particular, the elastic nature of the rubber constituent of the surface may have an effect on the rebound of the Clegg hammer upon impact if a lighter hammer was used. Studies are variable in the usage of different hammer weights, for example, Chivers and Aldous (2003) used a 2.25kg hammer to test an Australian football pitch, whereas Aldous *et al.* (2001) used a 0.5kg hammer to test recreational playing fields, suggesting that different hammer weights are suited to different sports surfaces.

1.4.2 Traction

The traction of a surface indicates how an athlete interacts with the surface in a horizontal plane, and originally equipment designed to measure traction was designed to mimic a player wearing a studded boot as opposed to smooth soled shoes (Baker, 1989). Traction is a definite requirement of any sports surface because it enables the athlete to grip the surface and prevents the athlete from slipping or falling (Chivers and Aldous, 2003). Equally though, and especially in equestrian sports such as show jumping where the horse lands heavily, there must not be excessive amounts of traction, since some slip of the hoof is required in order to prevent concussive effects on the limbs (McClinchey *et al.,* 2004).

Equipment for measuring rotational traction was developed in 1975 and has since been used to test sports surfaces such as greyhound tracks (Baker and Firth, 2002), cricket and Australian football pitches (Chivers and Aldous, 2003) and recreational sports grounds (Spring and Baker, 2006). The equipment consists of a long shaft connected at one end to a steel disk, and at the other end to a handle. The steel disk is weighted down onto the surface, although weights vary from study to study. Baker and Firth (2002) used a weight of 30kg on a greyhound track. Alternatively, Gibbs (2002) used a weight of 40kg on recreational sports turf. The weights used in both of these studies may have been chosen to try to replicate the load exerted on a surface by a human athlete. In terms of measuring an equine surface though, the load could not be replicated given the size of the athlete. As a consequence, any measurements made with the traction apparatus should be considered as relative measurements of the surface itself, not replication of an equine loading pattern.

The steel disk and weights of the traction apparatus are held in contact with the surface and force is applied to the handle. The moment or torque required to turn the handle and thus shear the surface is measured with a torque wrench (Canaway and Bell, 1986). For human sports surfaces such as football pitches the disk may be studded with circular studs to represent a player’s footwear (Cannaway, 1992; Chivers and Aldous, 2003). When testing equestrian surfaces however, it is unlikely that the same disk would provide an accurate comparison to the movement of the horse, and therefore other disks would need to be tested. There are two examples of disks used on equestrian surfaces, both developed on a watered sand and rubber surface, one which compares better to the shape of the horses’ feet, and another which is designed to penetrate an equestrian surface to a similar depth the hoof would penetrate during movement, however these too would need to be pilot tested on a synthetic equestrian surface to determine the ideal base plate for that specific surface.

1.4.3 Resistance to Penetration

Resistance to penetration is directly linked to surface hardness and compaction. Ishaq *et al.* (2001) suggested that as the hardness and compaction of soils increased, the resistance to penetration also increased. Similar effects were also noted by Saffih-Hdadi *et al.* (2009), when measuring the penetration of compacted soils by roots. In equestrian sports though penetration must be measured separately in order to give an indication of the depth to which the hoof will penetrate the surface during breakover and subsequently the ability of the horse to propel the body weight in a forward direction (Peterson, 2008). In relation to the specific synthetic equestrian surface, the resistance to penetration may be difficult to determine accurately due to the fibres within the surface. As previously discussed, fibres come in two forms, short polypropylene fibres (Gibbs, 2002) and mesh fibres (Beard and Stiffers, 1993). If a penetrometer was to hit one of the mesh fibre elements, it is likely that this would prevent the penetrometer moving to as greater depth than if it did not touch it, and this is a key point to consider in designing and using such equipment on a surface that contains fibres.

Two penetrometers were available for the present study, which were a Proctor penetrometer and a Longchamp penetrometer. A Proctor penetrometer consists of a spring dynamometer with a scale on the stem which indicates the amount of pressure required to penetrate a surface to a depth of 5cm when pressure is applied to the handles. The Proctor penetrometer is ideal for profiling the resistance to penetration of a surface at different depths. The main limitation of the Proctor penetrometer is that it is a highly subjective piece of equipment, and the results may be affected by the researcher. A Longchamp penetrometer uses a 1kg weight which is dropped from a height of 1m onto a needle measuring $1cm^2$, a scale is used to measure the total penetration of the surface after three consecutive drops in a single position. It was originally designed to be used at Longchamp Racecourse in France, in order to test the going of the course (France Galop, 2008). The design of the Longchamp penetrometer means that it is more objective in its use, since it does not rely on the researcher to penetrate the surface in the same way the Proctor penetrometer does. Neither of the penetrometers discussed have been used to test a synthetic equestrian surface, therefore both should be pilot tested on the surface to determine the ideal one to use on that specific surface.

Myerscough College in Lancashire has an indoor international arena which has a sand, fibre, rubber and wax equestrian surface. At present there has been no investigative work on the specific surface and therefore the primary aim of this study was to characterise the surface itself before moving the focus of the college's research programme onto the effect of the surface on the horse. In order to do this a suite of tests were validated on the surface, and then used to measure the hardness, traction and resistance to penetration of a 20m x 40m dressage arena, before and after a preliminary, unaffiliated dressage competition. Further laboratory analysis of the surface components was then used to aid the explanation of results obtained within the arena.

1.5 Aims and Objectives

Aim One

To assess the reliability of a suite of mechanical tests of hardness, traction and resistance to penetration, using a Clegg hammer, traction apparatus and Longchamp and Proctor penetrometers, for use on a sand, fibre, rubber and wax equestrian surface.

Objective One

To take a measurements of hardness, traction and resistance to penetration on a sand, fibre, rubber and wax equestrian. The variations of the Clegg hammer to be tested were the drop height and weight. The variations of the traction apparatus to be tested were the base plate and weight. There were two types of penetrometer to be tested.

Hypothesis One

There will be a significant difference between the equipment variables indicating a specific method of using the equipment on the sand, fibre, rubber and wax equestrian surface.

Aim Two

To determine the effects of preliminary, unaffiliated dressage competitions on the mechanical properties of a sand, fibre, rubber and wax equestrian surface.

Objective Two

To take measurements of mechanical properties before and after six preliminary, unaffiliated dressage competitions and determine any significant differences between those measurements.

Hypothesis Two

There will be a significant difference between the measurements of mechanical properties taken before and after the competition. It is hypothesised that the hardness of the surface will increase, traction will decrease and penetration resistance will increase from measurements taken before competition to measurements taken after the competition

2.0 Equipment Validation

The equipment was tested on a synthetic equestrian surface, containing sand, fibre, rubber and wax, within Myerscough International, indoor arena, as detailed in Chapter one. The surface was supplied by a leading U.K. manufacturer of equestrian surfaces. The same manufacturer provided the grading equipment required to maintain the surface. The equipment consisted of a harrow which worked to a harrow depth of approximately five centimetres. Prior to the onset of the pilot study, the surface was prepared by arena personnel, using the grading equipment. Observations during the grading process revealed that two to three passes were made across the surface with the grader. Two Clegg hammers, a 0.5kg and 2.25kg, and a range of drop heights, 0.15m, 0.25m, 0.35m, 0.45m and 0.55m, were tested. Standard traction apparatus was tested with two different traction plates, under weights of 10kg, 20kg, 30kg and 40kg. Plate A was shaped to mimic a horseshoe, and Plate B was designed with three rectangular protrusions in an attempt to penetrate the surface. Longchamp and Proctor penetrometers were both used to test the penetration resistance of the surface. The purpose of the tests was to determine the most reliable method of using each piece of equipment on the synthetic equestrian surface. The results of the equipment validation were analysed using an Analysis of Variance (ANOVA) calculation on the statistical software package Minitab© 14.

2.1 The Clegg Hammer

Surface hardness was tested using a Clegg Hammer produced by Simon Deakon Instruments CIST/882 (Plate 2.1). The equipment consisted of a hollow guide tube and a weight with an integrated accelerometer. The weight was dropped through the guide tube from a specific height, and the peak deceleration was recorded upon impact with the surface. This value was displayed on a digital display meter (See Guide to using a Clegg Impact Tester Appendix 3.0, section A). Two Clegg hammers were tested for the equipment validation, a 0.5kg and 2.25kg hammer. Baker *et al* (2007) suggested that Clegg hammers incorporating heavier weights produced results with least variability. This minimal rebound is the result of the heavier hammer contacting the surface with a higher energy. Baker *et al.* (2001b) also suggested that selection of a Clegg hammer weight should take into consideration any damage which could be caused to the surface when the weight was dropped. This equipment has previously been used in studies to test football pitches (Spring and Baker, 2006) and recreational sports grounds (Aldous *et al.* 2001) among other human sports pitches.

Plate 2.1 The 2.25kg Clegg Impact Tester. A = Digital display meter. B = 2.25kg weight fitted with an accelerometer. C = Hollow guide tube.

The Clegg Hammers were both tested from five different drop heights between 0.15m and 0.55m (Table 2.2.1), and therefore encompassed a range of heights used in previous studies. Such studies have used drop heights which ranged from 0.3m (Baker and Firth, 2002) to 0.55m (Spring and Baker, 2006). The heights used in the present study were defined by measuring and marking the Clegg Hammer using coloured electrical tape. Fifty individual measurements were taken using each Clegg Hammer, from each of the drop heights, ensuring that there was no overlap of the measurements. The area used measured 2.0m x 2.0m and the coordinates of the centre of this area were determined by using random number generation.

2.1.1 Results of Clegg Hammer Validation

There were significant associations between the drop height and the final hardness measurement, and also the weight of the Clegg hammer and the final hardness measurement (P<0.001) (Table 2.1.1). A higher hardness value was recorded when a greater drop height was used. The use of the 0.5kg Clegg hammer also indicated this greater hardness. Overall the results show that only a specific drop height and Clegg hammer weight would be suitable for the synthetic surface. In order to determine the most reliable combination, the sample variance of the data was analysed. The sample variance indicates the amount of variability in the data. When converted to a standard deviation by the square root function, it shows the spread of the data about the mean. Ideally, the equipment variable which was chosen should have had a low sample variance on the prepared surface, and therefore any variance which was calculated after the dressage event could be attributed to changes throughout the event as opposed to equipment variability.

Table 2.1.1 - Mean hardness (Gravities) for each drop height and Clegg hammer weight on the synthetic equestrian surface. N = 50.

	Mean Hardness (Gravities)	
Drop Height (m)	**0.5kg**	**2.25kg**
0.15	54 ± 1	26 ± 0.5***
0.25	70 ± 1	44 ± 0.6***
0.35	113 ± 2	56 ± 1***
0.45	100 ± 1	76 ± 1***
0.55	108 ± 1	85 ± 1***

± indicates standard error
***** indicates significant difference between results obtained at each drop height at P<0.001 level**

There were significant differences (P<0.001) between the sample variance of the results for each hammer weight (Table 2.1.2). The sample variances calculated from data obtained with the 2.25kg Clegg hammer were lower than those obtained using the 0.5kg Clegg hammer. These results support work by

Baker *et al.* (2007) which also suggested that the heaviest hammer weights produced results with least variability due to greater energy upon contact with a turf surface.

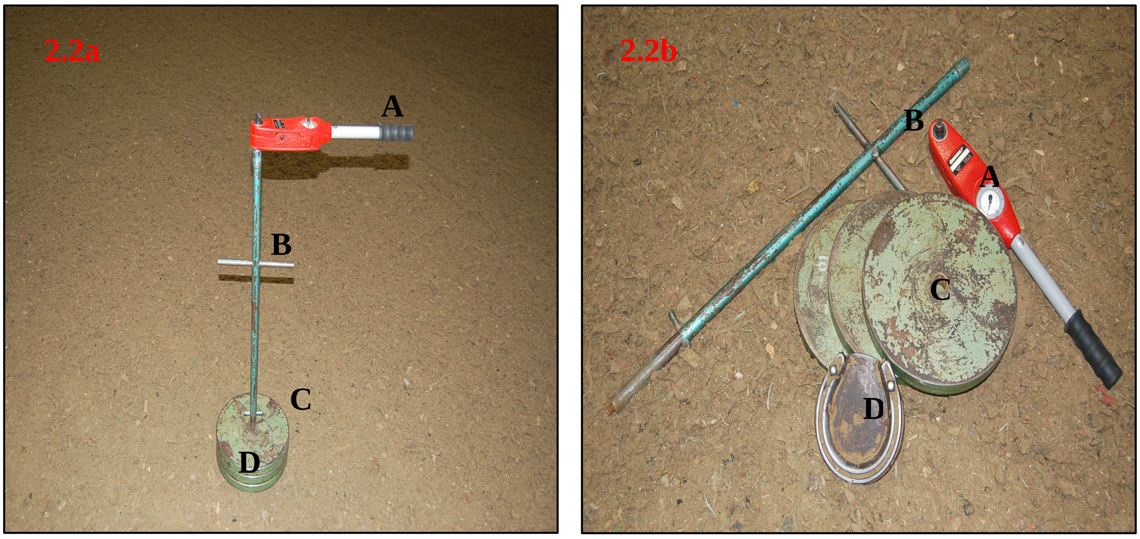
Table 2.1.2 – Sample variance (G^2) of data obtained with a 0.5kg and a 2.25kg Clegg Hammer, dropped from heights ranging from 0.15m to 0.55m onto the surface. N = 50

Weight / Height	0.15m	0.25m	0.35m	0.45m	0.55m
0.5kg	82	69	129	98	100
2.25kg	16	19	59	94	106

The lowest sample variance of the 2.25kg Clegg Hammer was determined at a drop height of 0.15m (Table 2.1.2), however, drop height was found to be significantly related to the hardness reading obtained ($P<0.001$). This is consistent with suggestions made by Baker *et al.* (2001b) that increasing the drop height of the Clegg Hammer increases the energy with which it contacts the surface and therefore produces a greater hardness measurement. There were significant differences between the data obtained at the two lowest (0.15m and 0.25m) and the three highest (0.35m, 0.45m and 0.55m) drop heights ($P<0.001$), therefore only the three highest drop heights were considered further. No significant association was found between the sample variances of the three highest drop heights ($P>0.05$). It was therefore decided that a drop height of 0.45m would be used as this was the standard height marked on the 2.25kg Clegg hammer by the manufacturer.

2.2 Standard Traction Apparatus

Traction was measured in terms of the rotational force required to turn a weighted base plate, using a standard torque wrench (Plate 2.2a and b). The equipment was adapted from a studded boot apparatus described by Cannaway and Bell (1986) which was used to determine the maximum horizontal force a football player could apply to a turf pitch before slipping. The apparatus was dropped from a set height of 0.2m onto the synthetic equestrian surface and a force was applied to the handle of the torque wrench in order to turn the base plate. A reading was then taken from the torque wrench and recorded (See Guide to using a torque wrench, Appendix 3.0, section B). The area in which the data was collected was determined by generating random coordinates. Baker and Firth (2002) and Spring and Baker (2006) have previously used this method to test cricket pitches and recreational sports grounds, respectively.



Plates 2.2a (Assembled apparatus) and 2.2b (Apparatus components) – Standard traction equipment
A = Torque Wrench
B = Connecting section with handles to lift the equipment
C = 10kg weights
D = Base plate

Two base plates were examined during the validation. Plate A was shaped to mimic a shod equine hoof to generate interactions similar to an actual hoof (Plate 2.2c). Plate B had three rectangular protrusions designed to gain better penetration of the top layers of the surface (Plate 2.2d). Chivers and Aldous (2003) and Spring and Baker (2006) have both used base plates designed to mimic the action of studded football boots, it was therefore important to determine the ideal base plate for use on a synthetic equestrian surface.

Plates 2.2c and 2.2d – Base plate A (left) designed to mimic the shape of a shod equine hoof, and plate B (right) with three rectangular protrusions designed to penetrate the surface.

Twenty repetitions were carried out with each base plate using different weights ranging from ten to 40 kilograms (Table 2.2.1) to determine the optimum base plate and weight combination. Studies have used weights from 30kg (Baker and Firth, 2002) to 40kg (Gibbs, 2002), suggesting that the weights of 30kg and above were favoured in previous studies. One important factor to note is that a direct comparison cannot be made between the results obtained using the traction apparatus versus the average weight of a horse. As a result, the measurements obtained should be used as a relative indication of how the surface changes throughout competition, further kinetic research would be required to determine how this would affect the horse. In addition, the equipment had never been used on a synthetic equestrian surface, and so all plate and weight combinations were initially tested during the validation work.

2.2.1 Results of Traction Apparatus Validation

There were significant associations between the base plate, and the weight of the traction apparatus, and the final traction measurement ($P<0.01$) (Table 2.2.1). There was a linear relationship between the weight used and the traction measurement obtained. Coulomb's model of shear stress, used regularly in developing equations for determining soil shear strength, states that as normal stress increases, the effective stress also increases linearly (Ley *et al.,*1993). This result indicates that both the base plate and weight combination would affect the final results.

Table 2.2.1 – Mean traction (Nm) for each plate and weight combination measured using a torque wrench on the synthetic equestrian surface. N = 20.

Plate	Weight (kg)	Mean Traction (Nm)
A	10	13.5 ± 0.3**
A	20	18.4 ± 0.3**
A	30	21.9 ± 0.2**
A	40	27.1 ± 0.3**
B	10	9.5 ± 0.5**
B	20	19.5 ± 0.4**
B	30	28.0 ± 0.7**
B	40	30.4 ± 0.6**

± indicates standard error
**** indicates significant differences between measurements obtained with each combination at P<0.01 level**

A two-way ANOVA was carried out on transformed data since the raw data was non-normal. The results of this showed that individual readings obtained were significantly associated (P<0.001) with the original base plate and weight combination. When analysed individually, there was a significant effect of base plate on the sample variance (P<0.05), but no significant effect (P>0.05) of the weight on the sample variance (Table 2.2.2). It was decided therefore that Plate A should be used due to the significantly lower sample variance of results, under a weight of 30kg as this had been used successfully in previous studies on different surfaces, such as Baker and Firth (2002). It must be noted that the chosen weight does not accurately replicate the weight of a horse, and therefore any measurements made with the traction apparatus should be considered relative measurements of the surface, and not a replication of the movement of a horse.

Table 2.2.2 – Sample variances (Nm^2) of the data obtained using Plates A and B under weights ranging from 10kg to 40kg. N = 20

Sample variance	10kg	20kg	30kg	40kg
Plate A	1.7	1.9	0.9	1.3
Plate B	5.9	3.6	9.3	7.2

2.3 Longchamp and Proctor Penetrometers

The resistance to penetration of the synthetic surface was initially measured using both a Proctor penetrometer (Plate 2.3a) EL29-3925 (ELE International, Hertfordshire) and a Longchamp penetrometer (Plate 2.3b). The Proctor penetrometer consists of a spring dynamometer with a scale indicating pressure on the stem of the handle with increments ranging from ten to 150 pound force (lbf). Seven interchangeable, circular needles were available of which only the smallest (0.0625 inch²) was suitable for penetrating the surface, therefore there was no requirement to test the different equipment variables of the Proctor penetrometer (See Guide to using a Proctor penetrometer, Appendix 3.0, section C). The Longchamp penetrometer consists of a square 1cm² needle onto which a one kilogram weight is dropped from a height of one metre. The total penetration depth was measured after three consecutive drops in a single position. Since there was only one standard way of using the Longchamp penetrometer there was again no requirement to test the equipment variables (See Guide to using Longchamp Penetrometer, Appendix 3.0, section D).

The Longchamp and the Proctor penetrometers are designed to indicate the amount of resistance to penetration a surface offers. The Longchamp penetrometer indicates the depth which the surface is penetrated by the needle, therefore the greater the depth of penetration, the lower the equivalent resistance to penetration is. Conversely, the Proctor penetrometer indicates the maximum amount of force required to penetrate the surface to a depth of five centimetres, therefore the greater the force that is required, the greater the equivalent resistance to penetration is.

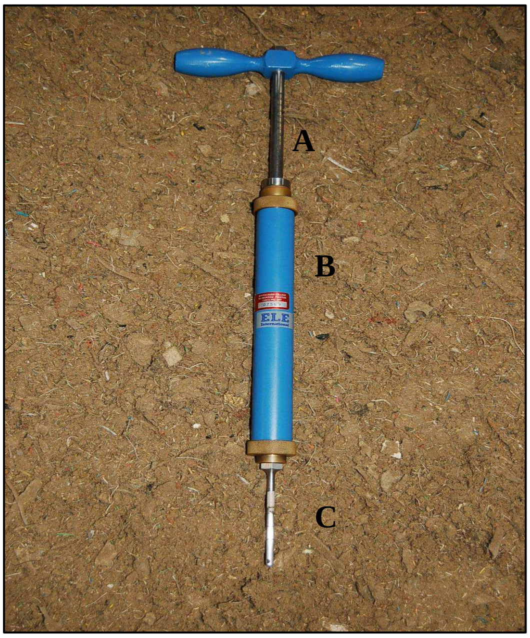


Plate 2.3a - Proctor Penetrometer A = Scale on the stem of the handle. B = Spring Dynamometer. C = Needle which penetrates surface

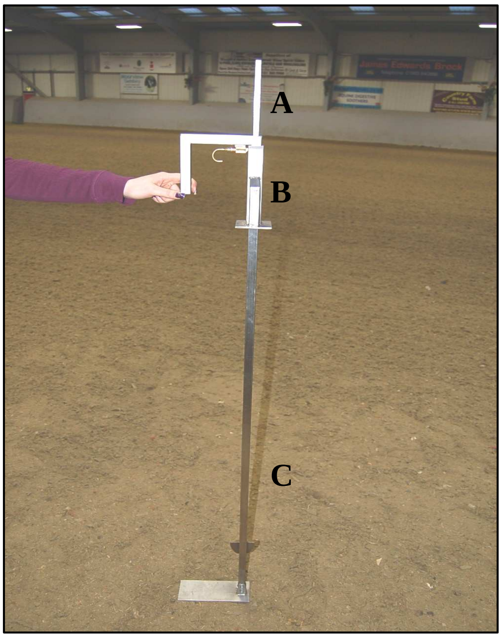


Plate 2.3b - Longchamp Penetrometer A = Scale in 0.5cm increments. B = 1kg weight at a height of 1m. C = 1cm^2 needle which penetrates the surface

2.3.1 Results of Longchamp and Proctor Penetrometer Validation

The comparison of the equipment variables in for the Clegg hammer and traction apparatus relied on the fact that each set of measurements, for each variable, had the same units. This meant that a direct comparison of variances could be made since the context of the variance was the same. Direct comparison of the Longchamp and Proctor penetrometers was not as straight forward though since the units of measurement were different and therefore the context of the two data sets were different. In order to compare the two pieces of equipment it was necessary to calculate the coefficient of variance for each set of data. The coefficient of variance is defined as a dimensionless number (it is a pure number with no units) and therefore places both sets of data into one context, making the data comparable. The equation used to determine the coefficient of variance is as follows;

Coefficient of variance = Mean / Standard Deviation

In order to obtain a coefficient of variance for this equipment, four sets of twenty repetitions were made with each piece of equipment within one area of the arena (mean values for each data set are located in Appendix 4.0). The positions at which these measurements were taken were generated using random number generation. There was a significant (P<0.001) difference between the coefficients of variance, of the four data sets for the Longchamp and Proctor penetrometers (Table 2.3.1). The Longchamp penetrometer showed a lower coefficient of variance, suggesting that it produced more reliable results, and therefore only this penetrometer was tested further.

Table 2.3.1 – Coefficient of variances of the Longchamp and Proctor penetrometers. N = 20

	Coefficient of Variance	
Data Set	**Longchamp Penetrometer**	**Proctor Penetrometer**
1	4.1	28.5***
2	10.5	19.5***
3	3.6	27.3***
4	4.45	24.0***

***** indicates a significant difference between data sets at the P<0.001 level**

2.4 The Optimum Number of Repetitions with Each Piece of Equipment

It was important to ensure that during the main study sufficient data was collected, within a limited time of approximately one hour, to produce an accurate representation of the mechanical properties within the arena. In order to do this, an optimum number of repetitions were calculated by carrying out analysis of the sample variance of data groups with different numbers of repetitions. Hardness measurements were grouped in intervals of ten repetitions, up to fifty repetitions. Traction and penetration resistance measurements were grouped in intervals of five repetitions, up to twenty measurements.

2.4.1 The Clegg Hammer

A different number of repetitions of the Clegg hammer have been used in various studies. Chivers and Aldous (2003) suggested that four measurements would be suitable in one area of an Australian Rules football pitch. Alternatively Spring and Baker (2006) used six repetitions in one area, on a winter games pitch. There was no significant association (P>0.05) between the number of repetitions and the sample variance, for the synthetic equestrian surface, suggesting that a sample size fewer than ten repetitions per area would produce reliable results, this is in support of the studies detailed previously. A further analysis was therefore carried out on the raw data for repetitions 1-10. The analysis showed that there was no significant association (P>0.05) between the repeat number and the reading obtained. Based on the findings from the validation work and other studies it was decided that a set of five repetitions would be carried out in each position in the dressage arena in the final study.

2.4.2 The Traction Apparatus

A direct comparison of number of repetitions with the traction apparatus cannot be made between this and other studies, due to the unique nature of the base plate. In 1992, Cannaway suggested that four repetitions would be a suitable number of repetitions on a sand-based rootzone. More recently, Chivers and Aldous (2003) and Spring and Baker (2006) also used four repetitions. These studies used the studded boot base plate on the apparatus. There was no significant association (P>0.05) between the number of repetitions and the sample variance of data obtained on the synthetic equestrian surface. A further analysis was therefore carried out on the raw data for repetitions 1-5. The analysis showed that there was no significant association (P>0.05) between the repeat number and the reading obtained. Based on the findings from the pilot work and other studies it was decided that a set of five repetitions would be carried out in each position in the dressage arena in the final study.

2.4.3 The Longchamp Penetrometer

There was no significant association between the number of repetitions and the sample variance obtained (P>0.05) when using the Longchamp penetrometer. A further analysis was therefore carried out on the raw data of repetitions 1-5. The analysis showed that there was no significant association (P>0.05) between the repeat number and the reading obtained. It was decided that a set of five repetitions would be carried out in each area of the dressage arena in the final study.

2.5 Summary of Equipment Validation Results

The first aim and objective detailed in section 1.5 was to validate a suite of mechanical tests on a synthetic equestrian surface by testing a range of equipment variables. The analysis of data during this validation showed that for each piece of equipment there was a specific method of use that was most reliable for the specific surface. In the main study therefore, hardness was measured using a 2.25kg Clegg hammer, dropped from 0.45m. Traction was measured using Base Plate A, under a weight of 30kg. Penetration depth was measured using the Longchamp penetrometer. Measurements were repeated five times at each of the arena positions. A pilot study was undertaken before the main study commenced.

2.6 Pilot Study at a Dressage Event

The purpose of the pilot study was to use the equipment as detailed in section 2.5, and then use the results obtained to determine how many positions within the arena should be used in the final study in order to gain a valid result in the final study. In addition, this was also a prime opportunity for the author to train the research assistants in the correct way to use the equipment during the data collection process.

A single day of unaffiliated dressage was chosen, with levels ranging from Preliminary through to Medium level, and a total of 64 horses competing on the synthetic surface in one day. This day was chosen to ensure that the surface would be used consistently over several hours, since competitors were performing a test every 3-4 minutes. There was therefore no opportunity for the surface to be prepared between competitors, and so the measurements obtained were a true representation of how the surface changed with use.

The arena surface was prepared before the competition, using the standard grading equipment provided by the surface manufacturer. The surface was passed two to three times with the grading equipment, by arena personnel, and was graded to a depth of five centimetres. Measurements of hardness, traction and resistance to penetration were taken before the event, on the prepared surface, and after the event, when the final competitor had finished. These times were chosen so that there was no interference with the running of the competition, at which the competitors had set times to perform the dressage test. The measurements were taken in accordance with the results of the equipment validation, detailed in section 2.5. There were 24 sets of coordinates at which measurements were taken and five repetitions were made with each piece of equipment at each coordinate. The coordinates used in the study were determined using a stratified random sampling method, and were measured by pacing out within the 20m x 40m arena.

2.6.1 Results from Pilot Dressage Event

The measurements of the hardness of the surface did not change significantly after the dressage competition ($P>0.05$) suggesting that the surface did not compact significantly under the weight of the horses. Alternatively, the equipment may not have been sensitive enough to detect subtle changes within the surface hardness. This is something which will be discussed further in chapter 6. The traction of the surface decreased significantly, suggesting that there was an increased likelihood of a slip at the end of the competition compared to the start. The penetration depth increased significantly ($P<0.001$), which suggests that the resistance to penetration decreased, and therefore there was an increased likelihood that the hoof would penetrate the surface more at the end of the competition compared to the start of the competition (Table 2.6.1). These results for traction and penetration depth were the opposite of what was expected. Under compaction conditions it was expected that the traction would increase since the sand particles would be forced closer together and therefore would be more likely to shear against one another (Whalley *et al.,* 1995). Similarly, Ishaq *et al.* (2001) reported that penetration resistance should increase as compaction occurred, whereas the equestrian surface had a decreased resistance to penetration and hence increased total penetration depth.

Table 2.6.1 - Mean differences between measurements of the mechanical properties of a synthetic equestrian surface before and after an unaffiliated dressage competition.

Measurement	Mean Before the Event	Mean After the Event
Hardness (Gravities)	111 ± 0.4	112 ± 2.2
Traction (Nm)	22.4 ± 0.09	21.8 ± 0.13 ***
Total Penetration Depth (cm)	1.5 ± 0.02	1.7 ± 0.04 ***

± indicates standard error
***** Denotes a significant difference in the mean after the event, at the P<0.001 level**

The coefficient of variance of the data was used to indicate how the variability of the surface altered from measurements taken before the competition to after the competition. There was a significant decrease in the coefficient of variance of hardness (P<0.001) suggesting that the surface was more uniform with regards to this property. There was a significant increase (P<0.01) in coefficient of variance of traction, suggesting that traction of the surface became more variable. No significant changes in the coefficient of variance occurred for the total penetration depth, suggesting that the competition itself did not have a significant effect on the variability of the penetrability of the surface (Table 2.6.2).

Table 2.6.2 - Changes in the coefficient of variance of the mechanical properties of a synthetic equestrian surface, after an unaffiliated dressage competition

Measurement	Coefficient of Variance Before Event	Coefficient of Variance After Event
Hardness (Gravities)	28.7	4.7***
Traction (Nm)	21.4	50.0 **
Total Penetration Depth (cm)	4.7	3.8

****indicates a significant change of variance after the competition at the P<0.01 level**
*****indicates a significant change of variance after the competition at the P<0.001 level**

2.6.2 Differences between Arena Zones

Dressage tests follow a set route throughout the arena, often leaving a track around the edge of the arena which is used heavily, and an area in the centre of the arena which has less usage. It was therefore decided that the data from the pilot study should be split into two 'zones' to determine if there were any differences between the mechanical properties measured within the two areas. There were eight coordinates analysed in Zone 1 and 16 coordinates analysed in Zone 2 (Figure 2.6.2.1).

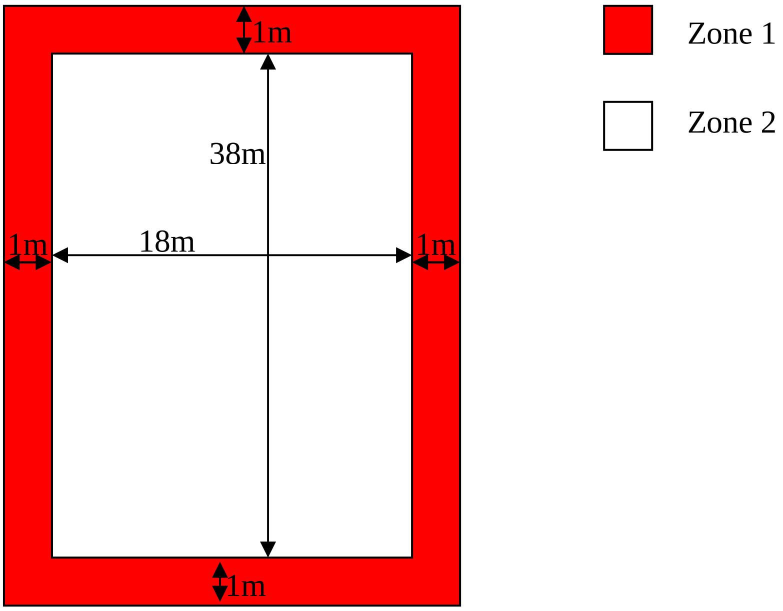


Figure 2.6.2.1 - Illustration of arena divisions

There were no significant differences between the measurements of mechanical properties obtained in each of these zones (Table 2.6.2.1). The results indicate that the all areas of the arena were used equally, however since there were more coordinates analysed in zone one compared to zone two it was decided that for the main study the arena would still be divided, but with an equal number of coordinates in each zone. In addition, a single preliminary dressage test would be videoed in order to determine how long horses spent in each zone, and if this correlated with the results obtained in each zone.

Table 2.6.2.1 - Differences in mean hardness, traction and resistance to penetration of a synthetic equestrian surface, split between Zone 1 and Zone 2 after an unaffiliated dressage competition.

Measurement	Mean Zone 1	Mean Zone 2
Hardness (Gravities)	112 ± 4	112 ± 3
Traction (Nm)	21.8 ± 3.2	21.8 ± 0.2
Total Penetration Depth (cm)	1.8 ± 0.06	1.7 ± 0.05

± indicates standard error

2.7 Summary of Pilot Study Results

The results of the pilot study show that the equipment can be used effectively to detect changes in the mechanical properties of the synthetic equestrian surface. In order to ensure that in the main study enough data would be collected to obtain a valid result, a power analysis was run based upon the results of the pilot study using the software package Minitab© (Table 2.7). The corresponding number of arena positions was determined by dividing the sample size by the number of repetitions which would be made at each individual position, and then rounding up to the nearest whole number. Five repetitions were made with each piece of equipment, therefore each sample size was divided by five. The Clegg hammer was found to require the largest sample because it had the highest standard deviation, however given the sheer volume of arena positions that would require testing it was decided that the result for the penetration depth would be used. The result for the penetration depth showed that a total of 32 arena positions would require analysis in the final study.

Table 2.7 - Details of power analysis carried out on data obtained during preliminary, unaffiliated dressage competition, used to determine the required number of arena positions.

Measurement	Power Value	Difference Between Means	Standard Deviation	Sample Size	Corresponding Number of Arena Positions
Hardness	0.95	1	23.75	14661	2933
Traction	0.95	0.6	1.38	139	28
Penetration Depth	0.95	0.2	0.49	157	32

3.0 Methods (Main Studies)

The main studies were carried out over six preliminary unaffiliated dressage competitions from January to June 2009. The dates of the competitions were chosen in order to regulate the level of the dressage competitions, and also in accordance with the schedule of Myerscough international arena.

The arena positions were separated into two zones of 16, the first 16 were evenly spaced around the track area, and the last 16 were placed using a stratified random sampling method (Figure 2.7). The coordinates were paced in the same manner as the pilot study and marked using numbered markers, each of which was colour coded. Zone one was coded in red cardboard and zone two was coded in blue cardboard. The placement of the markers was carried out by the researcher before and after every competition. The study was carried out in exactly the same way during each competition in order to ensure repeatability and reliability of the results, with measurements taken before and after each competition. Surface preparation was undertaken in the same manner as the pilot study, using two to three passes of the grading equipment to a harrow depth of approximately five centimetres. In addition to the main data collection, measurements of temperature were taken throughout the competition using Tinytag© dataloggers, in order to determine whether there was any effect of temperature on the results. Mechanical properties were measured as follows;

3.1 Hardness

Hardness was measured using a 2.25kg Clegg hammer which was dropped from a height of 0.45m which was defined by a white line on the red weight. Five repetitions were made at each arena position. The Clegg hammer was placed in the area around the coordinates, ensuring that there was no overlap of the area each time the Clegg hammer was placed down.

3.2 Traction

Traction was measured using the standard traction equipment, comprising base plate A, designed to mimic a shod hoof, under a weigh of 30kg, and dropped onto the surface from a height of 0.2m. Five repetitions were made at each arena position. The traction apparatus was dropped around the coordinate markers, ensuring that there was no overlap each time the equipment was dropped.

3.3 Resistance to Penetration

Resistance to penetration was measured using the Longchamp penetrometer. Five repetitions were made at each arena position. The Longchamp penetrometer was placed around the coordinate markers, ensuring that there was no overlap each time the equipment was placed. In addition the Longchamp penetrometer was placed in areas where the surface was even, in accordance with the manufacturer's guidelines (France Gallop, 2008).

3.4 Temperature Data Collection

In addition to the measurements of the mechanical properties of the surface, temperature measurements were recorded throughout the competitions using Tinytag© dataloggers. Tinytag© dataloggers have been used in numerous studies requiring accurate temperature data, for example, determining the efficiency of heating systems in low-income homes (Hong *et al.,* 2009). The dataloggers were loaded into individual, waterproof containers and were capable of recording up to 16000 measurements per session (Tinytag, 2009).

Measurements were taken 10cm below the surface, at ground level, and at heights of 0.5m and 2m above the surface. Two dataloggers were set at each height, at opposite ends of the arena. Position one was at the farthest end of the arena, away from the main entrance, and position two was on a diagonal to position one, closer to the main entrance. The positions were chosen to ensure that there was minimal chance of a horse or rider coming into contact with the dataloggers. The dataloggers which were above the surface (at ground level and 0.5m above the surface) were protected within a tube, and the datalogger 2m above the ground was placed on top of a ledge which ran around the perimeter of the arena. Dataloggers were programmed to take a temperature reading every two seconds throughout the competitions; this gave a total of 7200 measurements, per datalogger throughout each of the dressage competitions. The dataloggers were programmed in this way using Tinytag© software, in order to ensure that measurements were taken from the throughout the whole of each completion.

3.5 Video Analysis of a Preliminary Dressage Test

In order to determine the amount of time horses spent on the track and central areas during a preliminary dressage test, a single test was videoed. The white boards, used to mark out the arena were used as reference points in order to determine where the track area finished and the central area began (plate 3.5). The video was then played back, and the amount of time spent on the track and the central areas was calculated by timing the amount of time spent either side of the reference points. This was then compared to the data obtained from the mechanical property measurements in the main study. The purpose of this part of the data collection was to try to determine if there was an association between the amount of time spent in a certain area of the arena in a certain pace, and the mechanical properties which were observed within those areas.

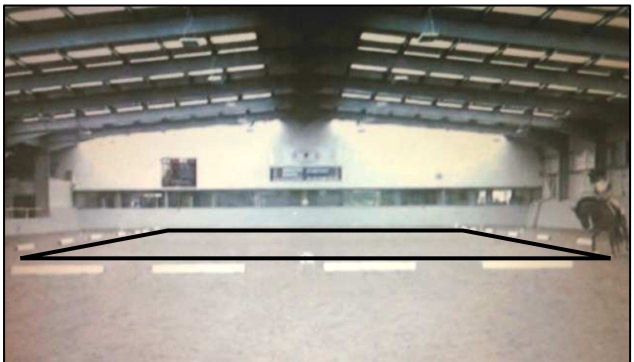


Plate 3.5 – Screen shot of the video analysis. Black line illustrates the boundary used to determine where the 1m track area ended and the central area began. The horse and rider are on the track area in this image.

3.6 Determination of Surface Use between Dressage Competitions

In order to determine whether there was a relationship between the results obtained at each individual dressage competition and how the arena was used between dressage competitions, it was important to record how the arena was used between competitions. Myerscough International Arena keeps up-to-date, hourly records of all users of the arena. The total number of hours the arena was used each day was therefore split between three levels of intensity, as follows –

Intensity One = Individual (Private) Use – Lowest level
Intensity Two = Student Use
Intensity Three = Competition Use – Highest level

This gave a total number of hours that the surface was used at each intensity, for the days between competitions. The total number of hours at each intensity was then multiplied by the level of intensity, and then all three intensity levels were totalled, to give an overall intensity of use for that time period.

The total intensity for each time period was then compared to the initial measurements of hardness, traction and resistance to penetration, on each date.

3.7 Statistical Analysis

The raw data was analysed using Analysis of Variance and Kruskal-Wallis tests. General linear models were also used to determine whether the data could be grouped. A chi-squared analysis was used to determine if there was any association between the results obtained in the track and central areas. A p-value of $P<0.05$ was used to indicate a significant result.

4.0 Results

The hardness, traction and penetrability of the synthetic equestrian surface changed significantly from measurements taken before to measurements taken after all six dressage competitions. There were significant differences between the track and central areas of the dressage arena. Temperature differences occurred throughout each dressage competition and arena usage altered between competitions.

The results which are presented in the following sections regarding differences between the measurements taken before and after each competition, and differences between the track and central measurements have all been categorized as follows;

* indicates significant difference between means at the $P<0.05$ level

** indicates significant difference between means at the $P<0.01$ level

*** indicates significant difference between means at the $P<0.001$ level

Letters denote heterogeneity of original measurements at the $P<0.001$ level

4.1 Changes in the Mechanical Properties of a Synthetic Equestrian Surface

The hardness, traction and penetrability of the surface changed significantly from the measurements taken before each competition to the measurements taken after each competition. In addition, the mechanical properties of the synthetic surface measured before each competition changed significantly over six months from the first data collection on January 21st to the final data collection on June 24th.

4.1.1 Hardness

The mean hardness of the synthetic surface increased, from initial to final measurements, at all of the dressage competitions, with the exception of the competition on May 20th (Figure 4.1.1). On February 18th and March 18th the increase in mean hardness was significant ($P<0.05$) indicating that the surface did become significantly harder and more compact on these dates. On May 20th, the decrease in mean hardness was significant ($P<0.01$) indicating that the surface did become softer and looser on this occasion.

A secondary observation from this data set was that there was a significant decrease ($P<0.001$) between the initial hardness measurements from January 21st to June 24th. This produced five groups of results, labelled a-e in figure 4.1.1. The individual letters represent significant differences between data obtained on different dates, for example, the data obtained on February 18th showed that the surface was significantly harder than on January 21st ($P<0.001$) but there was no significant difference between the data obtained on March 4th and February 18th ($P>0.05$). Data represented by letters c, d and e show that the surface became significantly softer at each data collection ($P<0.001$).

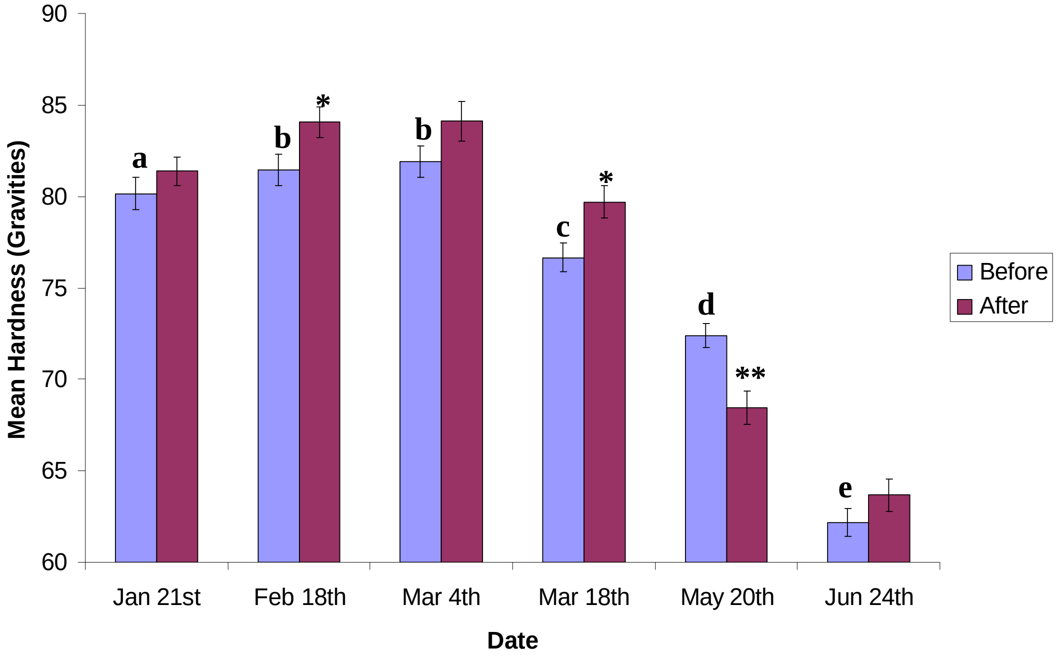


Figure 4.1.1 - Changes in mean hardness of a synthetic equestrian surface at six dressage competitions. Bars indicate standard errors.

4.1.2 Traction

There were an equal number of data collections in which the traction of the synthetic surface increased at competitions, as when the traction decreased at competitions, from initial to final measurements (Figure 4.1.2). Significant increases in traction occurred on January 21st ($P<0.05$), May 20th ($P<0.001$) and June 24th ($P<0.01$). Significant decreases in traction occurred on February 18th ($P<0.05$), March 4th ($P<0.001$) and March 18th ($P<0.001$). There was a significant effect of researcher on the traction results, which was likely to have been attributable to the varied results which were obtained, this is discussed further in Chapter six.

A secondary observation from this set of data was that there was a significant decrease ($P<0.001$) in the initial traction measurements, from January 21st to June 24th. The individual letters (figure 4.1.2) represent significant differences between data obtained on different dates, for example, the data obtained on February 18th showed that the surface did not exhibit significantly more traction than on January 21st ($P>0.05$), but there was a significant difference between the data obtained on March 4th and February 18th ($P<0.001$) Data represented by letters c, d and e show that the traction of the surface was significantly different at each of those data collections ($P<0.001$).

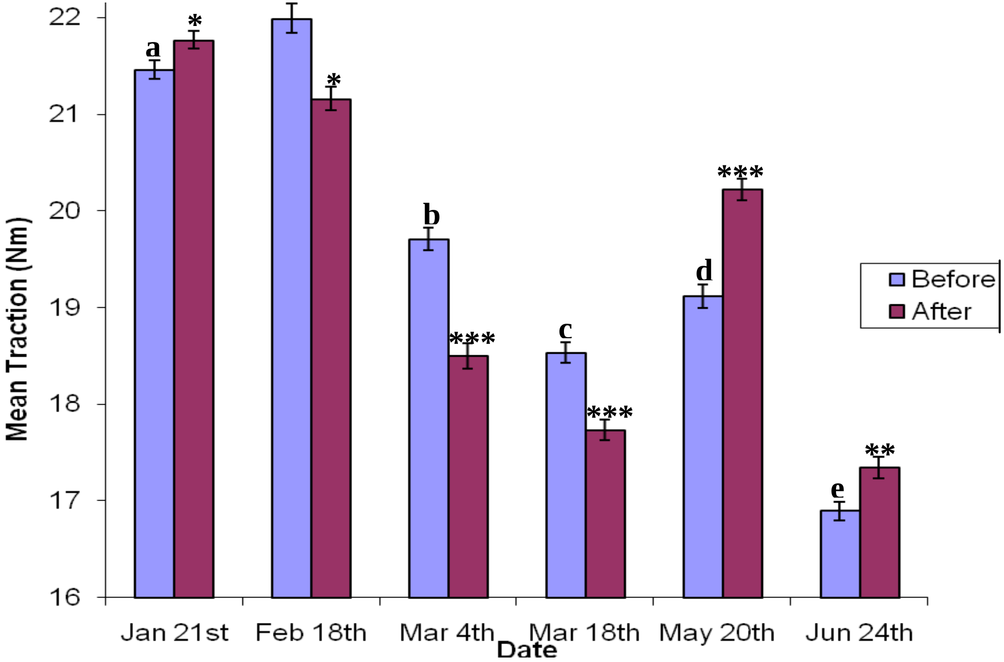


Figure 4.1.2 - Changes in mean traction of a synthetic equestrian surface at six dressage competitions. Bars indicate standard errors.

4.1.3 Penetrability

The total penetration depth of the synthetic surface increased from initial to final measurements, at five of the six dressage competitions (Figure 4.1.3). The increase in penetration depth was significant on January 21st ($P<0.001$) and May 20th ($P<0.05$) indicating that the surface became significantly softer and more penetrable on these occasions. There was a single day, March 4th when the total penetration depth decreased significantly ($P<0.01$), indicating that the surface became harder and less penetrable on this occasion.

A secondary observation from this data was that there was a significant increase ($P<0.001$) in the initial total penetration depth, from January 21st to June 24th. This produced four groups of results, labelled a-d in figure 4.1.3. The individual letters represent significant differences between data obtained on different dates, for example, there were no significant differences between the data obtained on the first three dates. Data represented by letters b, c and show that the penetration depth of the surface was significantly higher at each data collection

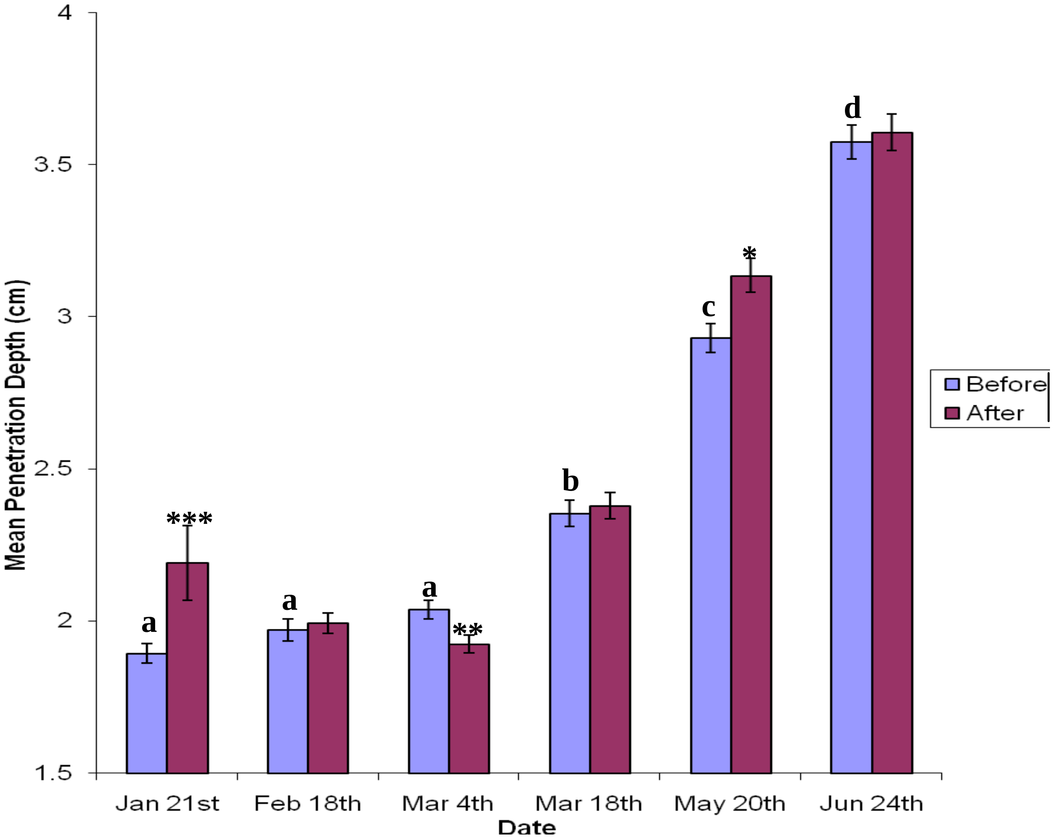


Figure 4.1.3 - Changes in mean total penetration depth of the synthetic equestrian surface at six dressage competitions. Bars represent standard errors.

4.1.4 Differences between the First, Second and Third Drops of the Longchamp Penetrometer

The use of the Longchamp penetrometer dictates that three consecutive drops of the one kilogram weight should be used in one position. This means that it is possible to gain an indication of how compact the surface is at different depths. When the synthetic surface was tested, the penetration depth which was achieved with drop one (Drop 1 – Starting Depth) of the Longchamp penetrometer was significantly different to the depths achieved with the second (Depth of Drop 2 – Depth of Drop 1) and third (Depth of Drop 3 – Depth of Drop 2) drops ($P<0.001$) (Table 4.1.4). The greatest penetration depth was achieved with the first drop of the weight, and the depths achieved with subsequent drops of the weight were always at least 0.5cm less than this value. This suggests that the surface was softer within the first 1-1.5cm depth, and the sub-layers were significantly harder, and this remained the case throughout all six of the dressage competitions.

Table 4.1.4 – Mean differences between the penetration depth achieved with the initial drop of a Longchamp penetrometer, and from the second to the third drops, on a synthetic equestrian surface. ± indicates standard errors.

Date	Drop 1 – 0 (cm)	Drop 2 – Drop 1 (cm)	Drop 3 – Drop 2 (cm)
Jan 21st	0.9 ± 0.02	0.6 ± 0.02	0.6 ± 0.04
Feb 18th	0.9 ± 0.01	0.6 ± 0.01	0.5 ± 0.02
Mar 4th	0.8 ± 0.01	0.6 ± 0.01	0.6 ± 0.02
Mar 18th	1.0 ± 0.02	0.7 ± 0.02	0.6 ± 0.02
May 20th	1.5 ± 0.02	0.8 ± 0.02	0.7 ± 0.02
Jun 24th	1.6 ± 0.02	1.0 ± 0.03	0.9 ± 0.02

4.1.5 Relationships between Mechanical Properties

There was a significant association found between the hardness and penetration depth of the synthetic surface ($r^2 = 0.96$, $P<0.001$), suggesting that as the hardness of the surface increased, the penetrability of the surface decreased (Figure 4.1.5a). There were no significant associations found between the hardness and traction (Figure 4.1.5b), or the traction and penetration depth (Figure 4.1.5c) ($r^2 = 0.29$, $P>0.05$ and $r^2 = 0.22$, $P>0.05$ respectively).

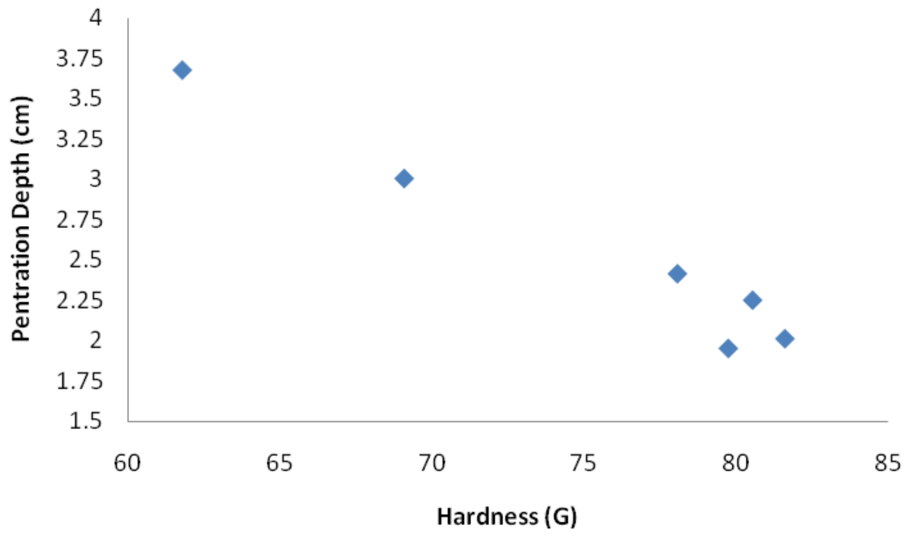


Figure 4.1.5a – Linear relationship between the Hardness and Penetration depth measurements taken at each dressage competition. $r^2 = 0.967$. $P<0.001$

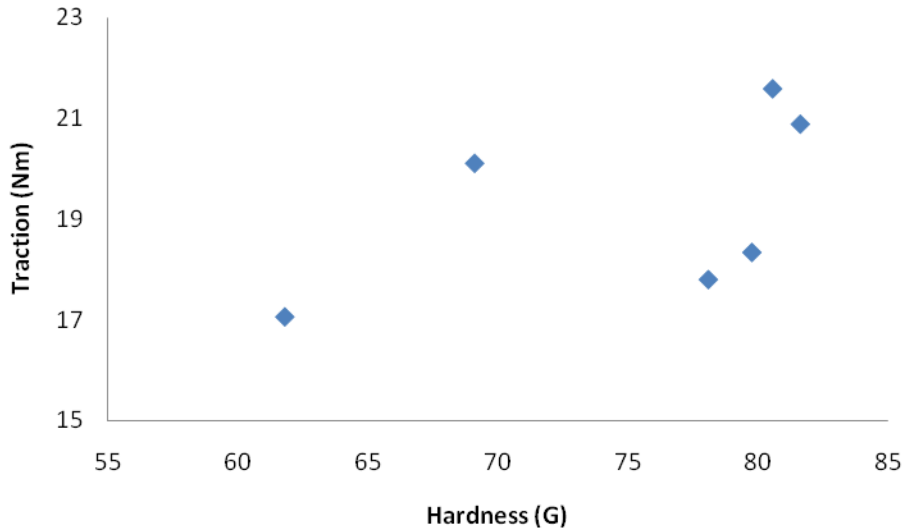


Figure 4.1.5b – Non-linear relationship between the Hardness and Traction measurements taken at each dressage competition. $r^2 = 0.29$. $P>0.05$

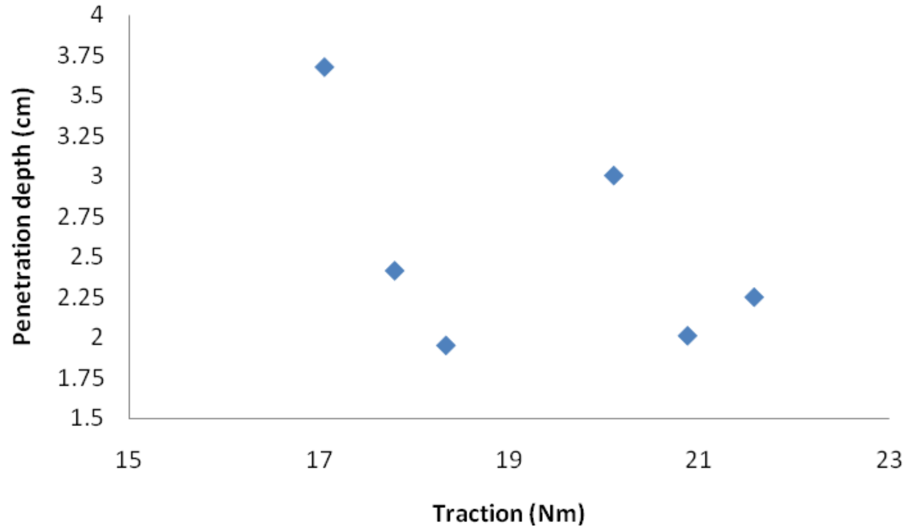


Figure 4.1.5c – Non-linear relationship between the Traction and Penetration depth measurements taken at each competition. $r^2 = 0.22$. $P>0.05$.

4.2 Measurement of Mechanical Properties of the Track and Central Area of a Dressage Arena

There were significant differences in the hardness, traction and penetrability measurements obtained in the track and the central areas, after each of the dressage competitions within the main study. The results in these sections can be related to the results of the video analysis (section 4.3).

4.2.1 Hardness

The mean hardness of the surface was higher in the central area compared to the track area of the arena on all data collections, with the exception of May 20th (Figure 4.2.1). This difference between the hardness measurements was significant on February 18th ($P<0.001$), March 4th ($P<0.01$) and June 24th ($P<0.05$), suggesting that the surface was significantly harder and more compact in the central area, and indicating that perhaps this area received more use than the track on these occasions. This is confirmed in section 4.3 in which the results suggest that a significantly greater amount of time was spent in the central area in the walk and trot paces.

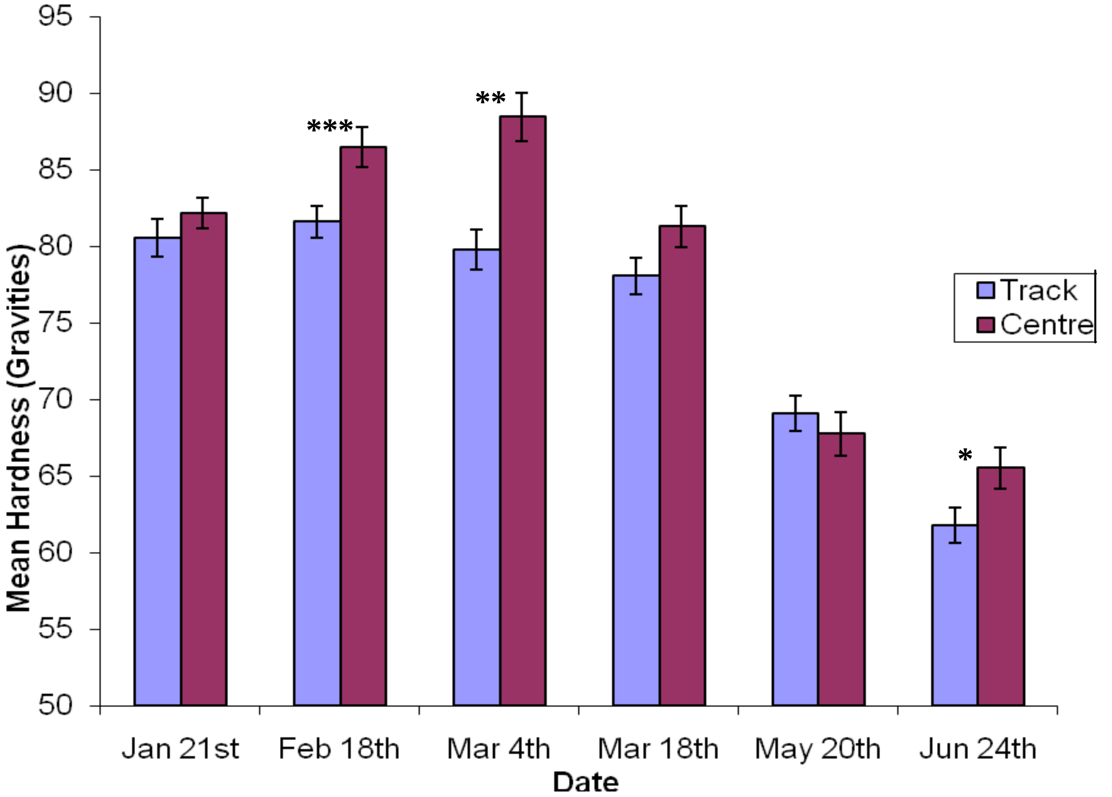


Figure 4.2.1 - Differences in mean hardness between the track and central areas of a dressage arena after a competition. Bars indicate standard errors.

4.2.2 Traction

The mean traction of the surface was higher in the central area compared to the track area of the arena at all of the competitions, with the exception of March 18th (Figure 4.2.2). This difference between the traction measurements was significant on February 18th and June 24th at the $P<0.05$ level. This result is related to the compaction of the surface, the central area received more work (section 4.3) and therefore was more likely to compact and show a higher level of traction. The results indicate that after the competition there was potentially more chance of a slip or fall occurring on the track area of the arena compared to the central area.

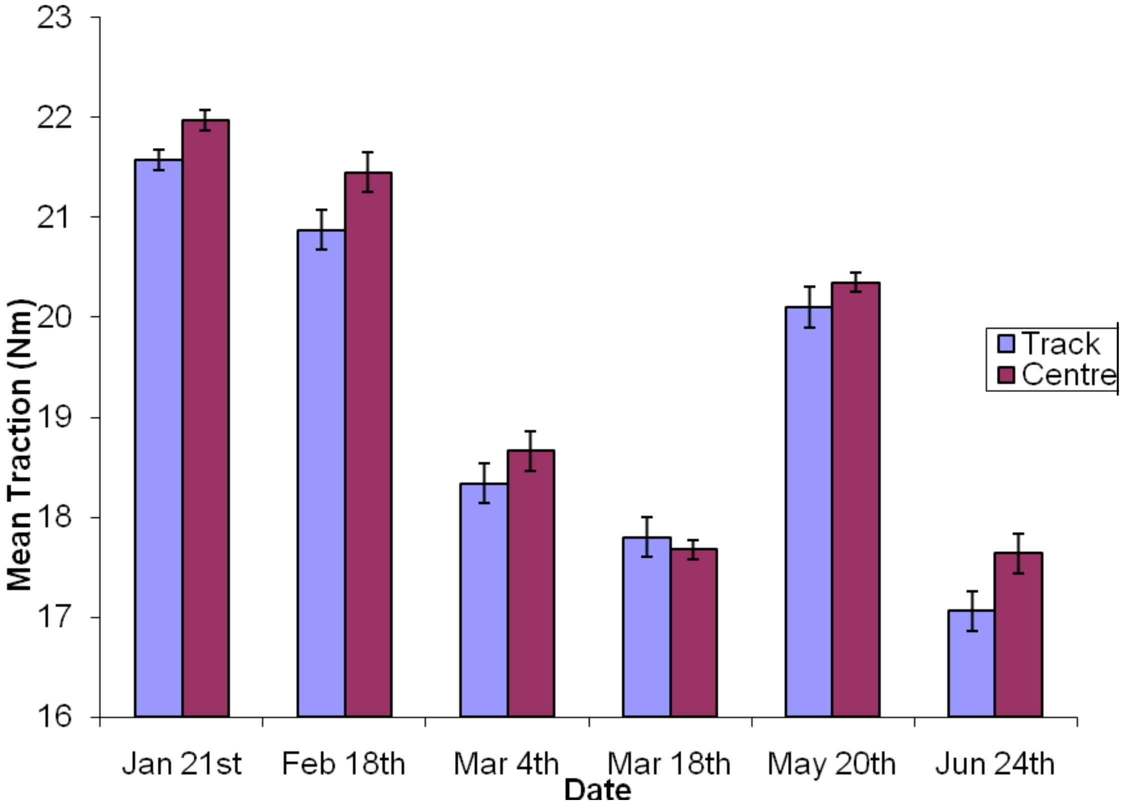


Figure 4.2.2 - Differences in mean traction between the track and central areas of dressage arena after competitions. Bars indicate standard errors.

4.2.3 Penetration Depth

The total penetration depth in the central area of the arena was smaller compared to the track area (Figure 4.2.3). On June 24th this difference in penetration depths was found to be significant ($P<0.05$) indicating that on this date the surface was significantly harder and less penetrable in the central area compared to the track. This is consistent with the central area becoming more compact due to a greater amount of time being spent there during a test (section 4.3). There was a single occasion, May 20th, when the total penetration depth was significantly greater ($P<0.05$) in the central area of the arena compared to the track area, suggesting that on this date the track area was harder and less penetrable than the central area.

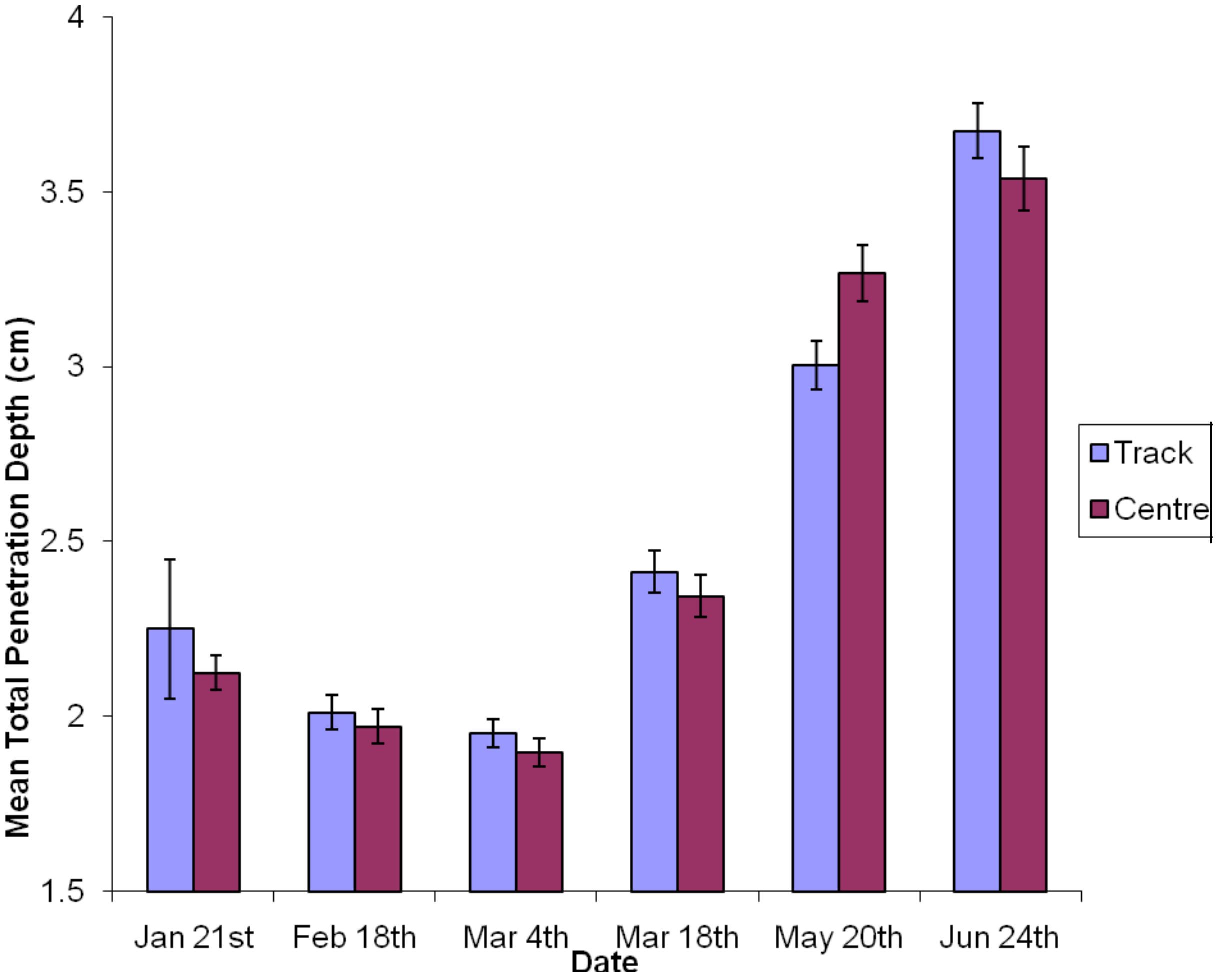


Figure 4.2.3 - Differences in mean total penetration depth between the track and central areas of a dressage arena after competitions. Bars indicate standard errors.

4.3 Assessment of the Percentage Usage of the Track and Central Areas during a Dressage Test

The results show that there was significantly less time spent on the track in walk and trot and more time spent in the central area in walk and trot than the calculated expected values (P<0.001) (Table 4.3). It also suggests that there was more time spent on the track in canter, and less time spent in the central area in canter than the calculated expected values (Figure 4.3). The data which was obtained from this part of the analysis is discussed further in relation to the mechanical properties in chapter six.

Table 4.3 – Total amount of time spent, by one horse and rider combination, in walk, trot and canter, in the track and central areas of a dressage arena when performing a preliminary, unaffiliated dressage test. Red numbers in brackets illustrate the expected values if each of the paces had been used equally on the track and the central areas.

	Track	**Centre**
Time in Walk (s)	31 (41)	31 (21)
Time in Trot (s)	75 (78)	43 (41)
Time in Canter (s)	54 (41)	10 (24)
Total Time (s)	160	84

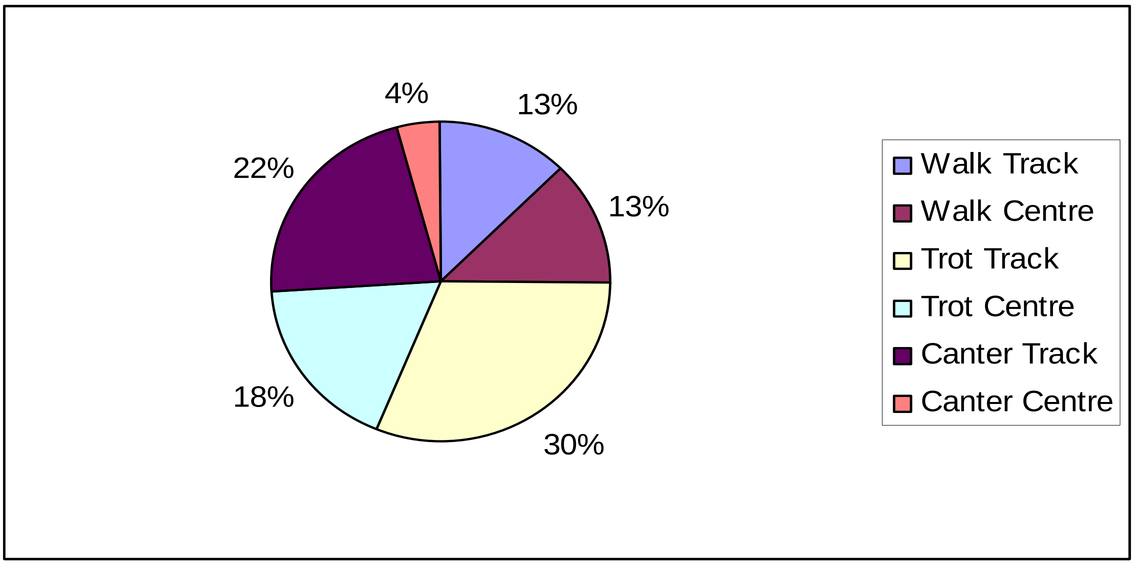


Figure 4.3 – Percentage of time spent in each walk, trot and canter, in the track and central areas of a 20m x 40m dressage arena during a preliminary, unaffiliated dressage test

4.4 Temperature Changes throughout Six Dressage Competitions

The results which were obtained in sections 4.1 – 4.3 indicated that all of the mechanical properties of the synthetic surface changed significantly from the first data collection on January 21st, to the last data collection on June 24th. It was possible that an external factor had some influence on the results, and therefore temperature measurements from each data collection were analysed. There were significant differences between the mean temperatures at each of the individual competitions ($P<0.001$) (Figure 4.4).

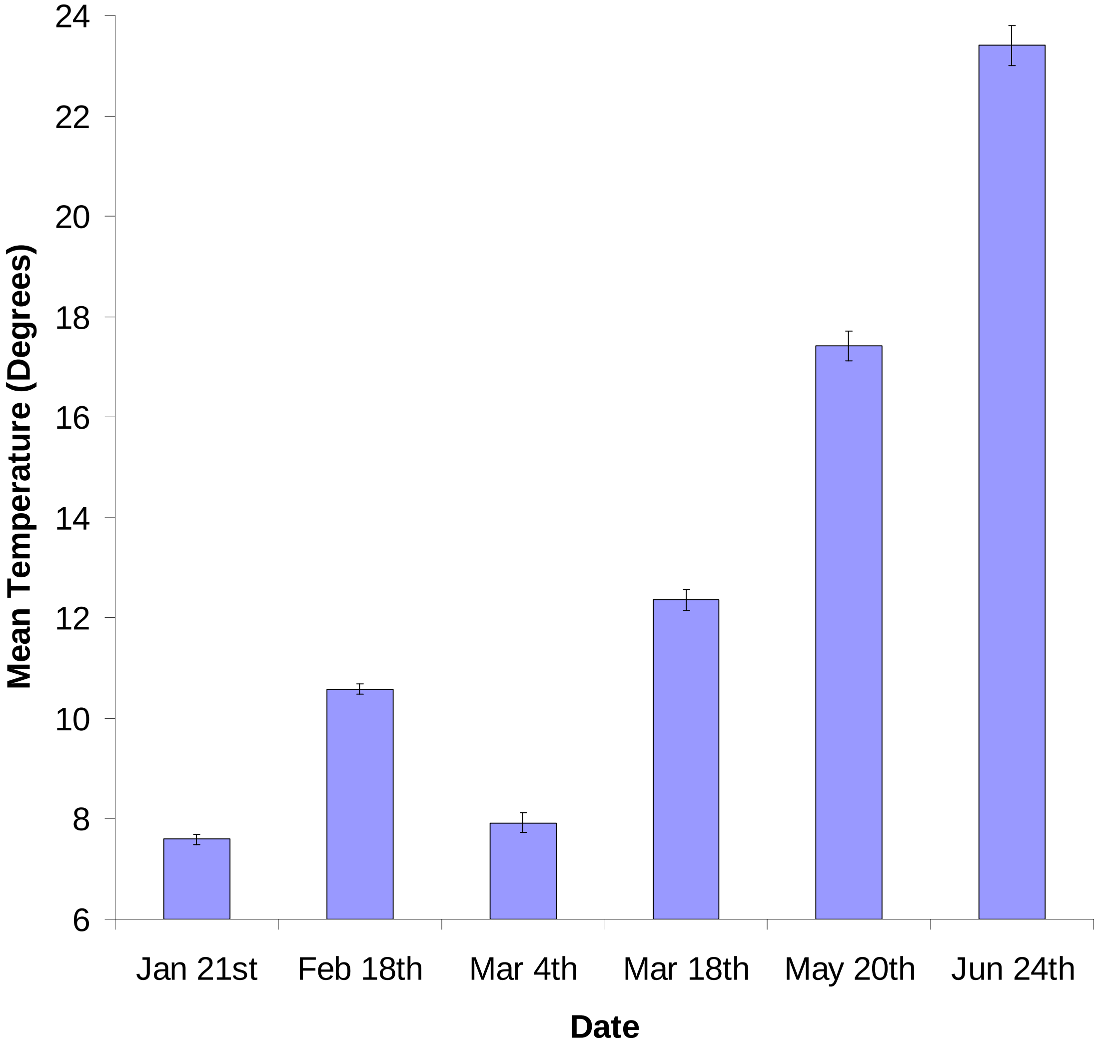


Figure 4.4 - Mean temperatures during six individual preliminary, unaffiliated dressage competitions, collected using Tinytag© data loggers, at eight positions in an equestrian arena. Bars indicate standard errors.

There were significant differences between the data obtained at positions one and two, detailed in section 3.4, ($P<0.05$) at all of the competitions, with the exception of March 18th. These differences were almost certainly due to the proximity of the dataloggers to the inner walls and external doors. The data loggers in position two were farthest from the dressage arena and closest to the open external doors, therefore for the purpose of this study, only the data obtained from position one was considered further.

4.4.1 The Effect of Data Logger Height on Temperature Readings

There were significant differences between the temperature readings obtained at each data logger height at all of the dressage competitions with the exception of May 20th. On January 21st and February 18th this result was significant at the $P<0.01$ level. On March 4th, March 18th and June 24th, this result was significant at the $P<0.001$ level (Table 4.4.1).

Table 4.4.1 – Mean temperatures reached daily at each data logger height

	Temperature (℃)			
Date	**2m Above Ground Level**	**0.5m Above Ground Level**	**Ground Level**	**10cm Below Ground Level**
Jan 21st	9.2 ± 0.02	9.4 ± 0.02	9.4 ±0.02	9.8 ± 0.02**
Feb18th	12.9 ± 0.02	12.5 ± 0.02	11.8 ± 0.02	11.7 ± 0.02**
Mar 4th	9.7 ± 0.02	10.1 ± 0.03	10.2 ± 0.03	10.9 ± 0.02***
Mar 18th	14.8 ± 0.02	14.5 ± 0.02	14.7 ± 0.02	14.3 ± 0.02***
May 20th	18.1 ± 0.01	18.3 ± 0.01	18.9 ± 0.01	16.7 ± 0.01
Jun 24th	23.7 ± 0.01	25.6 ± 0.01	22.9 ± 0.01	22.0 ± 0.01***

± indicates standard errors
**** Indicates significant differences between recordings at each height at the P<0.01 level**
***** Indicates significant differences between recordings at each height at the P<0.001 level**

4.4.2 The Relationship between Temperature and Mechanical properties

As the daily temperature increased over the six months of data collections, the hardness of the surface decreased. This was found to be a linear relationship ($r^2 = 0.93$) between the hardness of the surface and the daily temperature ($P<0.01$) (Figure 4.4.2a).

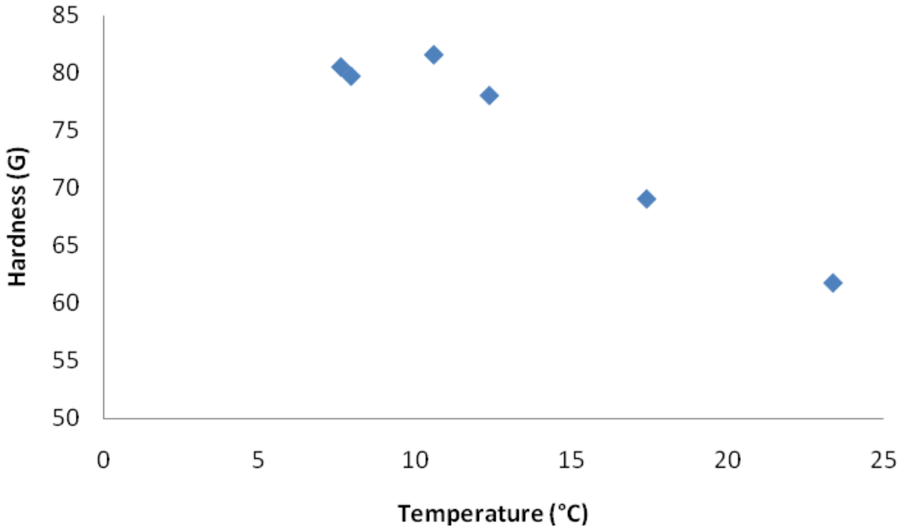


Figure 4.4.2a – The linear relationship observed between the initial hardness measurements at each competition, and the corresponding daily temperature. $r^2 = 0.93$ $P<0.01$

There was no significant association found between the traction of the surface and the daily temperature ($P>0.05$) (Figure 4.4.2b) and the relationship was non-linear ($r^2 = 0.29$), suggesting that daily temperature did not effect the traction of the surface.

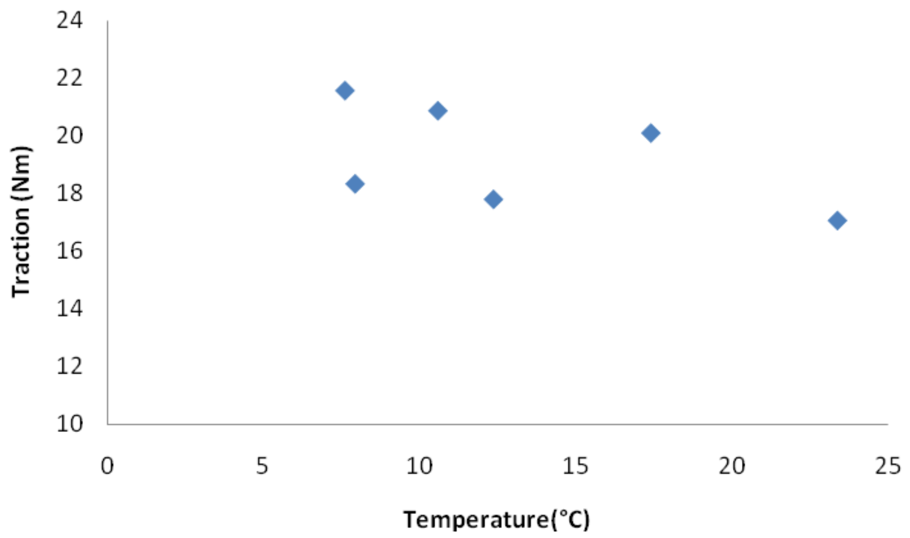


Figure 4.4.2b – The non-linear relationship observed between the initial traction measurements at each competition, and the corresponding daily temperature. $r^2 = 0.29$. $P>0.05$.

As the daily temperature increased over the six months of data collection, the total penetration depth of the surface decreased. This was found to be a linear relationship ($r^2 = 0.93$) between the total penetration depth of the surface and the daily temperature ($P<0.01$) (Figure 4.4.2c).

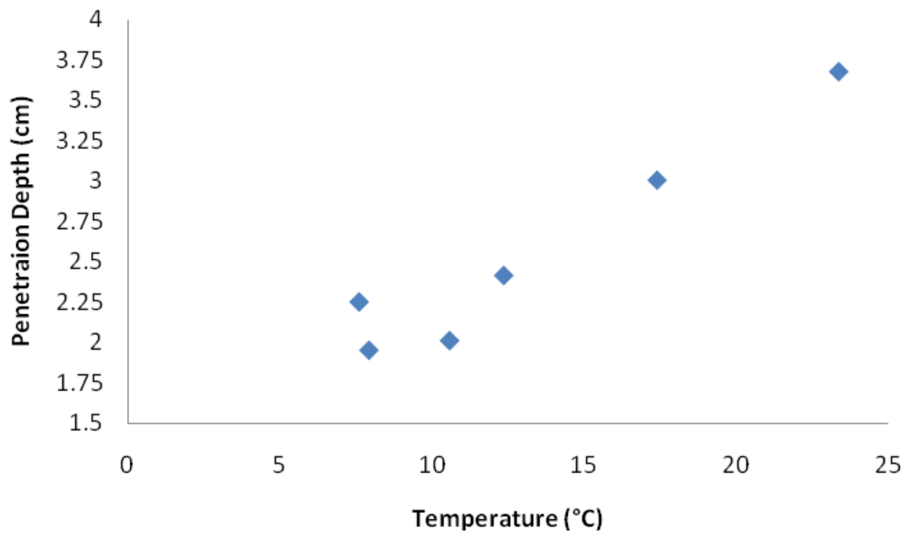


Figure 4.4.2c - The linear relationship observed between the initial penetration depth measurements at each competition, and the corresponding daily temperature. $r^2 = 0.93$ $P<0.01$

4.5 Usage of the Arena between Dressage Competitions

The total intensity of use on the dates preceding each of the unaffiliated, preliminary dressage dates (Table 4.5), was analysed with the original hardness, traction and penetration measurements taken on each of the individual dates. The results showed despite significant differences (P<0.001) between the intensity of use there were no significant associations between the intensity of use between competitions, and either the hardness, traction or penetration (P>0.05). This suggests that the results obtained from each data collection were unaffected by the cumulative effects of arena use. The surface preparation between each competition followed the same protocol as directly before the competitions. The surface was prepared daily, using two to three passes of the grader, harrowing to a depth of approximately five centimetres. Given that there was no significant association between the surface usage and the preparation it would suggest that the preparation was sufficient to maintain a uniform surface.

Table 4.5 – Total number of hours of use and intensity of use of a sand, fibre, rubber and wax equestrian surface between preliminary, unaffiliated dressage competitions.

Inclusive Dates		Total Number of Hours			
From	To	x Intensity 1	x Intensity 2	x Intensity 3	Total Intensity
Jan 1st	**Jan 20th**	12	170	329	**511**
Jan 21st	**Feb 17th**	25	263	553	**841**
Feb 18th	**Mar 3rd**	12	140	255	**407**
Mar 4th	**Mar 17th**	11	131	281	**422**
Mar 18th	**May 19th**	91	347	1040	**1478**
May 20th	**Jun 23rd**	53	359	375	**787**

4.6 Summary of Results

The second aim of the study, as detailed in section 1.5, was to determine the effects of preliminary, unaffiliated dressage competitions on the mechanical properties of a synthetic equestrian surface. The results suggest that the surface changed significantly at the dressage competitions. In addition, the data collections showed that there were significant differences between the mechanical properties of the track and central areas and significant changes in daily temperatures. There was no significant effect of the intensity of surface usage between competitions on the results collected at each dressage competition, indicating that the data was individual to each specific date.

5.0 Laboratory Analysis of the Surface

Two sets of laboratory tests were undertaken on samples of the synthetic surface taken from the International arena. The purpose of the laboratory analysis was to further explain and validate the results of the mechanical testing in the arena. The first laboratory test was used to determine the components of the surface, and the second test was used to determine the compaction ability of the surface at various temperatures.

5.1 Determining the Surface Components

Separation of surface constituents was undertaken in two phases. In order to determine the amount of sand, fibre and rubber within the synthetic surface, one kilogram of the surface was wet-sieved, using a 1mm sieve, and a fine jet of cold water. The sieved sand and the water was collected. The remaining fibre and rubber left in the sieve was removed and placed into pre-weighed metal drying tray, in a drying oven set at 100℃ to remove all moisture. The water and sand were then poured through a pre-weighed 63µm sieve. The sand remaining in the sieve was then placed in the same drying oven as the fibre and rubber for 24 hours. After 24 hours the drying tray and sieve were removed from the drying oven and placed in a dessicator to cool for one hour before re-weighing. The amount of sand, and fibre and rubber was calculated using the equation

Weight of sand/fibre/rubber (g) = (Weight of dried sample + Weight of dried container (g)) – Original weight of container (g)

The weight of the dried sand, and fibre and rubber was then expressed as a percentage of the original one kilogram of surface sample. This method was an adaptation of one described by Robertson *et al.* (1984) which recommended wet sieving over dry sieving since wet sieving produces results with less variation than dry sieving.

The sand constituent of the surface was viewed under a microscope at x100 magnification. The grains of sand were photographed and the images were compared to the images in figure 5.1 in order to determine the angularity of the sand grains.

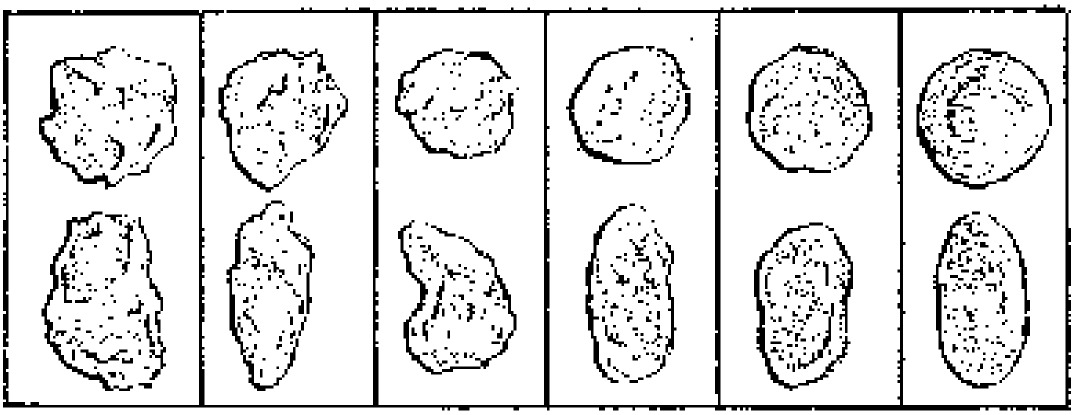


Figure 5.1 – Image of sand grains used to determine angularity. The top row illustrates grains with high sphericity and the bottom row illustrates grains with low sphericity. From left to right, angularity can be described as, very angular, angular, sub-angular, sub-rounded, rounded and well rounded. (Hopen, 2009)

Wax content of the surface was determined by heating a three gram sample of the surface to 400℃ in a pre-weighed crucible for twelve hours. Heating to this temperature removed all of the organic matter from the sample. Since the wax was palm oil based, this meant that all of the wax was burned off, leaving only the inorganic matter in the crucible. After 12 hours the crucibles were removed from the oven and placed in a dessicator to cool for two hours. The crucibles were then re-weighed and the weight loss calculated using the following equation –

$$\text{Weight loss (\%)} = \frac{\text{(Weight of crucible + Ash) – Original weight of crucible}}{\text{Original Weight of Sample}} \times 100$$

5.1.1 Results of Surface Components Analysis

The surface was separated by wet sieving in order to determine the exact ratio of the surface components, by mass, within the mixture. It was determined that the synthetic surface consisted of;

- 75% sub-angular sand particles with high sphericity by mass (Plate 5.1.1),
- 15% rubber (Plate 5.1.2) and fibre by mass(Plate 5.1.3c and d)
- 10% wax by mass

Plate 5.1.1 – Microscopic image of the sub-angular sand particles from a synthetic equestrian surface

Plate 5.1.2 – Small (right) and large (left) rubber pieces from a synthetic surface

Plates 5.1.3c and 5.1.3d – Two forms of fibre found in a synthetic equestrian surface. (c) Mesh fibres (d) Large felt fibres.

The components of a sports surface have a direct effect upon how the surface reacts to usage, therefore the results of this analysis are discussed further in chapter six in relation to the results of the mechanical testing of the surface.

5.2 Determining the Effect of Temperature on Compaction Ability

The results detailed in Chapter 4 showed that there was a significant increase in daily temperatures from the first data collection on January 21st to the last data collection on June 24th. In order to determine if this might have had a significant effect on the results of the mechanical testing, laboratory analysis was undertaken to determine the effects of temperature on the compaction ability of the synthetic surface.

In order to accurately replicate the mechanical properties of the sand, fibre, rubber and wax surface in a laboratory environment, the surface samples had to be prepared to the same bulk density as the surface was in the arena.

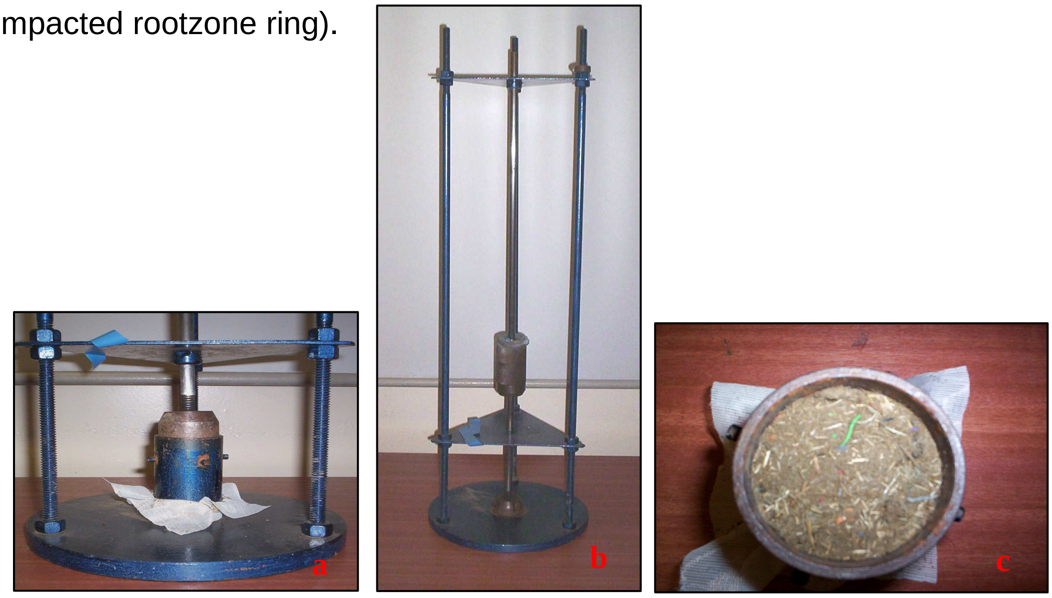
A core measuring 5cm in diameter and 4.5cm in depth was taken (Abu-Hamdah and Al-Jalil, 1999) from surface. A total volume of 88.4cm³ was collected. The total weight of the surface in the sample was 102.41g. The surface therefore had a bulk density of 1.16g/cm³. This figure was determined using the following equation -

Bulk density = Weight of sample/Volume of corer.

The rootzone rings that were used for the rest of the compaction work measured 5.5cm in diameter and 8cm deep, and therefore held a volume of 190.1cm³. In order to replicate the bulk density of the actual surface, a total of 220.29g was put into each rootzone ring. This weight was determined using the following equation -

Weight of Sample = Bulk density x Volume of rootzone ring

Rootzone rings, containing the surface at the appropriate bulk density were equilibrated to a range of temperatures 0, 10, 20, 30 and 40°C. The temperatures were chosen in order to cover a range which may be experienced within the British climate. Rootzone rings were subjected to 25 drops of a one kilogram weight, from a height of 45cm (Plate 5.2a shows a rootzone ring prepared for compaction under the weight and plate 5.2b shows the equipment used for this compaction). A measurement of compaction depth was taken using vernier callipers after each drop of the weight (Plate 5.2c shows a compacted rootzone ring).



Plates 5.2 (a-c) – (a) Rootzone ring in place and ready for compaction (b) complete compaction apparatus (c) A compacted rootzone ring

5.2.1 Results of Determining the Effects of Temperature on Compactability of the Synthetic Surface

There were significant differences (P<0.001) between the total compaction depth of the surface at 30℃ and 40℃ compared to t he lower temperatures (Table 5.2.1). When the temperature of the surface increased, the amount of compaction also increased. It is possible that this was related to the melting stage of the wax, however there is not enough evidence within this study to categorically say that this was the case.

Table 5.2.1 – Mean compaction depths of a synthetic equestrian surface in rootzone rings

Temperature of Surface (℃)	Mean Compaction Depth (mm)
0	8.9 ± 0.1
10	8.7 ± 0.6
20	8.9 ± 0.3
30	10.0 ± 0.5***
40	13.5 ± 0.9***

***** Indicates a significant difference in compaction depth compared to lower temperatures**

5.3 Summary of Results

The results of the analysis showed that temperature did have some effect on the surface particularly the higher temperatures. It would be a little ambitious at this stage to say that this would have a significant effect on the mechanical properties. The individual surface components could potentially have had an effect on the results which were obtained in the main study, but again this effect would have been one factor in a much broader and more complex picture.

6.0 Discussion

Murray *et al.* (2010) carried out a questionnaire-based study of dressage horses in the United Kingdom, and stated that surfaces which remain uniform are more likely to protect against injury in dressage horses. Riggs (2010) reported similar findings with regards to injuries sustained on equine racetracks. The description of the uniformity of a surface used for dressage, has until now been based upon anecdotal evidence and has not been quantified. The first aim of the study was therefore to validate a suite of mechanical tests to measure the hardness, traction and penetrability of a synthetic equestrian surface. The second aim was to use that suite of tests to determine the effects of dressage competitions on the mechanical properties of the same synthetic surface. The purpose of the study as a whole was to gain an insight into how and why the surface changed but more importantly, how those changes could be addressed, for example, Riggs (2010) suggested that surface maintenance was a key issue which needed addressing. It was found throughout the course of data collection and analysis that there were other considerations to take into account such as daily temperature, surface maintenance and surface components, which did not necessarily directly affect the results, but may have had some impact upon how the mechanical properties of the surface changed during use. This combination of variables significantly affected the synthetic equestrian surface and could potentially affect equine performance and the likelihood of injury, therefore this issue is also explored in the discussion. The overall picture is a key theme throughout the discussion and is therefore illustrated throughout with the use of diagrams.

6.1 Equipment Validation

The validation work (Figure 6.1.1) which was detailed in chapter two showed that using the Clegg hammer, traction apparatus and Longchamp penetrometer were valid methods of testing the specific synthetic surface used in the study, when the surface had undergone preparation to the specification of the surface supplier. On assumption which was made during the pilot work was that the surface was uniform throughout the testing. Future studies should use methods such as taking core samples at each test site in order to ensure that the surface is uniform throughout the layers and the whole of the arena.

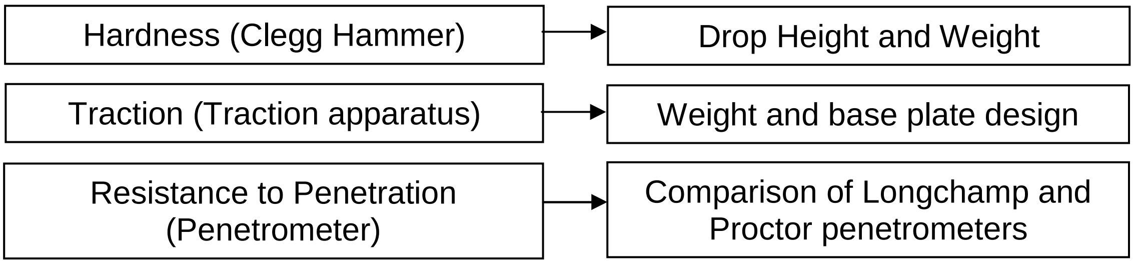


Figure 6.1.1 – The equipment validation process

There were specific equipment variables, or methods of use which produced results with a lower sample variance on the synthetic surface. With hindsight though, the lower sample variances obtained with each piece of equipment could also have been an indication that the equipment was not necessarily sensitive enough to measure the more subtle changes which could have occurred within the surface. This means that the results obtained in the main study, although significant, could have been more reliable if obtained with more sensitive equipment.

Baker *et al.* (2001b) reported that the Clegg hammer weight and drop height were closely correlated with the results obtained when testing a cricket pitch. The study on the synthetic surface found a similar result, in particular the heavier, 2.25kg Clegg hammer produced results with a lower sample variance.

Studies into traction of human surfaces such as Chivers and Aldous (2003) have previously used plates designed in the shape of a studded football boot in order to measure the interaction of football players with the pitch. Similar results were found in the present study in which the traction apparatus was found to have the lowest sample variance when fitted with a unique base plate shaped to mimic a shod hoof. This was an important outcome for the study since it showed traction base plate design may need to be carefully tailored to test specific surfaces. Observations during the data collection indicated that the reason for the differences between the variance for each base plate was due to the protrusions on Plate B. When the traction apparatus was dropped onto the surface when it was fitted with Plate B the protrusions did not penetrate the surface and therefore the equipment was rendered unstable on top of the surface. This therefore affected the sample variance of the results.

The Longchamp penetrometer was designed for use on a grass racetrack (France Galop, 2008) however the results from this study indicate that it could be used effectively on a prepared synthetic equestrian surface (as opposed to a surface which had been used). In particular this may be useful for industry personnel as it is a piece of equipment which is simple to use, and could therefore be used to test surfaces before competition to ensure that preparation is consistent across an arena.

The main study used each piece of equipment to the specification which was determined in the validation work (chapter two) on the surface when it had been prepared and also after it had been used for a preliminary, unaffiliated dressage competition. It was found that the Clegg hammer and the traction apparatus produced precise and reproducible results on a synthetic surface which had been used for a dressage competition. The results obtained using the Longchamp penetrometer showed more variability. This could suggest that the equipment was less precise and therefore limited in its use on a surface which had been used for competition, as opposed to on a prepared surface. It is likely that this occurred since the Longchamp penetrometer was designed for use on a level surface, in particular a turf surface (France Galop, 2008), and the synthetic surface was relatively uneven after the dressage competitions. This is a factor which would not have been known until the results of the main study had been analysed. Alternatively though, the Longchamp penetrometer could have been more sensitive to changes within the surface and the increase in variability mirrored the increase in variability of the surface.

The measurements which were taken throughout the study were designed to evaluate the mechanical properties of the surface. There were additional aspects to take into consideration which are shown in Figure 6.1.2. These factors are also discussed in relation to the results of the main study.

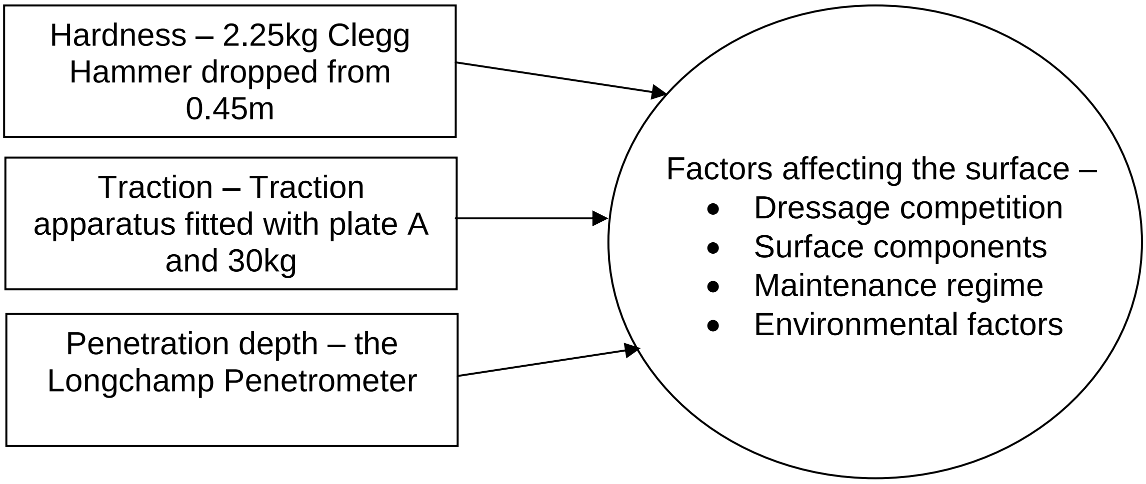


Figure 6.1.2 – Other factors to take into account in addition to the effects of the preliminary, unaffiliated dressage competition.

6.2 The Effect of Competition on the Mechanical Properties of a Synthetic Equestrian Surface

Surface hardness increased significantly on two occasions from the initial to the final measurements suggesting that the synthetic surface also became more compacted on these occasions. Whalley *et al.,* (1995) reported that compaction of particles occurs under imposed stresses, in this case under the weight of horses partaking in dressage competitions. The angular sand grains used in the construction of the synthetic surface may have been a significant contributing factor in this compaction. Yi *et al.* (2001) suggested that angular sand grains are highly likely to succumb to compaction due to the high numbers of air-filled pores between the sand grains. Under the weight of a moving horse, the sand grains are pushed into the air-filled spaces, and the air is removed. In comparison to rounded sands, angular sands are more likely to compact since rounded sand grains are more likely to move over one another as opposed to moving closer together (Yi *et al.,* 2001). This is discussed further in section 6.2.1 in relation to the components of the synthetic surface.

The central areas of the dressage arena exhibited greater hardness properties after competition compared to the track areas and on three occasions this result was found to be significant, February 18th, March 4th and June 24th. This would suggest that the central areas were used heavily throughout the competitions, and put under greater stress, than the track areas and therefore became more compact. Video analysis of a single preliminary dressage test showed that a horse and rider actually spent significantly more time on the track area than in the central area. This analysis opposes the results obtained from the surface as based upon the results of the mechanical tests the area which had been used most heavily should have been harder. Further analysis of the video revealed that significantly more time was spent in canter on the track area compared to the central area, and this therefore suggests that the surface did not simply react to the weight of the horse, but also to the type of movement being performed. The canter is a three-time gait and is therefore the only asymmetrical gait. This means that the horse uses a combination of single and paired leg movements, as opposed to the walk and trot which use either single leg movement or paired leg movement, but not a combination (Clayton, 1994). Based upon the results of this study, it would suggest that when a horse cantered over the synthetic surface the surface was more likely to become displaced as opposed to when a horse walked or trotted over it. It is possible that this displacement occurred during the propulsion of the horse's body weight (Merkens *et al.,* (1993). This would therefore explain why the track area was less compacted; as it received more canter work and therefore more displacement, compared to the central area. It would be a useful progression of this research to determine if there were significant differences between the data obtained on the straight sides of the track as opposed to the corners, since when cornering the propulsive forces are likely to act differently in order for the horse to maintain balance. In addition, the displacement of surface in the corners of an arena has been linked to loss of balance and the possibility of injury occurring (Dyson, 2002). The link between pace and surface displacement is also an important factor to note when preparing the synthetic surface for use in other forms of competition, such as show jumping, in which the predominant pace is canter.

There was limited conclusive data with regards to the daily changes in surface traction; results showed an equal number of data collections when traction either increased or decreased significantly from the initial measurements to measurements taken after the dressage competitions. One of the limitations of the study was that on the first three dates of data collection a different person operated the traction equipment for each set of measurements. This was simply due to the way in which the data collection was divided between the researcher and the research assistants. Additional data analysis prior to the fourth data collection, on March 18th, indicated that the equipment operator had a significant effect on the results (Appendix 5.0), The final three data collections were therefore carried out by the researcher only, and it was the data collected on these days that was considered further.

Results for the final three data collections indicated a significant decrease in traction on March 18th and significant increases in traction on May 20th and June 24th from the initial data collections to the data collections after each competition. It is possible that the traction results were related to the temperatures reached on each of the final three days of data collection, and this will be considered further in section 6.2.1 when the surface components are discussed. Since there is no traction performance standard to which synthetic equestrian surfaces are laid and maintained, it is difficult to determine whether the starting and ending traction measurements were too high, too low or at an ideal performance standard for dressage competitions, therefore it would be useful to continue this work in order to determine what that ideal level should be. One possibility for a continuation is to use motion analysis software to determine the amount of slip experienced on a surface prepared to a range of traction levels. Some preliminary work has already been produced on the same surface as the one used in this study which suggested that there was a significant difference between the amount of slip experienced, upon landing after jumping a one metre show jump, on the surface in a waxed state compared to an unwaxed state. Future work could use similar methods to determine the amount of slip experienced in different paces on surfaces prepared to a range of different traction levels.

The traction of the surface was greater in the central area of the arena, after the competition compared to the track area. On two occasions, February 18th and June 24th this result was found to be significant. Studies into compaction of soils have found that as pore sizes between soil particles decrease, the particles are more likely to shear against each other and therefore traction increases (Whalley *et al.* 1995). Given the angular nature of the sand particles within the surface it is likely that a similar principle can be applied, when the surface was more compact in the central area, the particles sheared against one another and were less easily displaced, thus causing the higher levels of traction.

Total penetration depth increased significantly on two occasions, after dressage competitions. This increase in penetrability was the opposite to what would be expected of a surface that had been compacted. Ishaq *et al.* (2001) noted an increase in penetration resistance and increased soil strength as compaction occurred. In the case of the synthetic equestrian surface, the increased penetration depth would suggest a decreased resistance to penetration. The results of a Longchamp penetrometer are affected by the evenness or level of the surface on which the penetrometer was stood (France Galop, 2008) and therefore to obtain a reliable reading the penetrometer must act on an even, level surface. After compaction under the horse, the synthetic equestrian surface was not even or level. This was due to the nature of the horses' movement and the shape of the hooves. In some areas the surface had more contact time with the hooves, and was therefore more compacted than in other areas. The surface surrounding the contact areas had become more displaced around the hooves. It is most likely that the penetration readings were not taken from the areas directly where the hooves fell, but from the surrounding areas where the surface was more even. In addition to this, the large pieces of fibre which were used in the construction of the surface sometimes prevented the needle of the Longchamp penetrometer from penetrating the surface completely under the weight of one kilogram, which would therefore give an inaccurate final reading. The combination of both of these factors would therefore reduce the overall reliability of this piece of equipment, and future studies should consider this limitation and explore alternative methods of measuring penetrability.

The total penetration depth of the central area of the arena was lower than the track area. Only one result, on June 24th, was found to be significant. These results are consistent with the arena becoming more compact in the central area. Given the lack of significant findings in these results it is likely that the evenness or level of the surface also influenced the final outcome in this analysis (France Gallop, 2008). As previously discussed, the results obtained from the Longchamp penetrometer were somewhat questionable since the penetrometer could not be placed completely randomly in a given area.

The mechanical properties of the surface are not discrete measurements, but are closely linked to each other. The hardness of the surface is directly linked to the compaction of the surface Yi *et al.,* (2001) and this is discussed in relation to the surface components in section 6.2.1. This compaction of the surface though is also linked to traction and resistance to penetration. Cruse *et al.* (1980) stated that the traction of a surface is affected by the angularity of the sand particles and therefore the ability of the particles to shear against one another. As a consequence of the compaction and increased hardness, the sand particles would have been closer together and more likely to sheer against one another, thus the surface traction would also have been greater. Ishaq *et al.* (2001) reported that as compaction of soils occurred, the resistance to penetration increased. In relation to the measurements taken during this study, regression analysis showed that there was a strong association between the hardness of the surface and the penetration depth achieved. There was however no significant association between the traction and the other mechanical properties, for this particular study.

The changes which were recorded in the mechanical properties were likely to have occurred due to the use of the surface for a dressage competition. As already mentioned though there were other factors to consider which could potentially have affected the way in which the changes came about. These factors are shown in Figure 6.1.2 and merit further discussion into how each could have affected the results, and how future analysis could be used to determine the actual affect.

6.2.1 Surface Components

When the synthetic surface was constructed, one of the key properties of the surface components should have been reduction of compaction; hence fibre and rubber additions were included within the overall mixture. Surface additions had only been proven to significantly affect surfaces which were used for human sports pitches such as those used in golf and football as detailed by Baker *et al.* (2001a) and Spring and Baker (2006) respectively. Laboratory analysis used wet sieving to separate the synthetic surface into its individual components. The analysis showed that the surface contained 75% sub-angular sand, 15% rubber and fibre and 10% wax by weight. Amendments are made to sand sports surfaces in order to improve properties such as hardness and compaction resistance, stability and durability. Spring and Baker (2006) tested fibre additions in winter games pitch rootzones and reported that there was a significant improvement in surface stability in the pitches containing the fibres. Baker *et al.* (2001a) carried out a study using rubber which was shown to improve the durability of sports pitches. The data collections at dressage events showed that the measurements taken after competition were significantly different from measurements taken on the prepared surface. It is possible that collectively, the surface components could be linked to the changes which were recorded.

The synthetic surface incorporated both large and small fibres which were designed to reduce the extent to which surface compaction occurred, and improve the overall stability of the surface. These effects have been noted in the construction of human playing surfaces including artificial turf surfaces and winter games pitches in studies by Baker (1989) and Spring and Baker (2006) respectively. Similar effects could have been noted in the synthetic equestrian surface; however the size of the athlete must be taken into account. Horses competing in the dressage competitions may weigh up to ten times the weight of a human, and therefore would impose significantly more stress on the surface.

Baker *et al.* (2001a) reported that the use of rubber within a surface with a sand dominated rootzone significantly improved the elastic strength of the surface, meaning that it was less likely to succumb to compaction and therefore surface hardness was reduced. Other studies on human sports surfaces such as games pitches and golf courses by Groenevelt and Grunthal (1998) and Rogers *et al.* (1998) have had similar results with regards to the surface hardness. There were significant differences in surface hardness from the initial measurements taken before the dressage competitions to the final measurements taken after the competitions, suggesting that the rubber amendments within the surface did not effectively reduce surface hardness. Similar questions therefore arise as with the fibre additions, in that the rubber may not have the same effect when subjected to the weight of a horse compared to the weight of a human. In addition, the rubber component of the surface could have been implicated in the changes in mechanical properties noted at different temperatures

Bridge *et al.* (2010) suggested that the waxes used within American synthetic race tracks had initial peak transitions in state between 22°C and 33°C, and final melting points ranging from 67°C to 84°C. The results from that study indicated that the waxes currently used in the specified surfaces were not stable enough to withstand daily temperature fluctuations, and therefore could affect surface mechanical properties. When a regression analysis was undertaken to determine if there was an association between the daily temperature and the mechanical properties it was found that there were significant associations between hardness and penetration depth, and daily temperature. It is therefore possible that the state of the wax within the synthetic equestrian surface could have altered over the course of the six data collections, as daily temperatures rose, thus affecting the mechanical properties of the surface. Binks and Rocher (2009) reported that commercial waxes have melting temperatures which range from approximately 50°C to over 100°C. Up to the individual melting temperature of a wax it undergoes a gradual decrease in solidity and stability. In relation to the synthetic surface, it is possible that the effects of the change in structure of the wax at increasing temperatures could decrease the overall stability of the surface, although it must be noted that in this study there were only two data collections (May 20th and June 24th) in which temperatures above 15°C were reached. In particular on June 24th, the surface was significantly less hard and significantly more penetrable. It also exhibited significantly lower levels of traction, suggesting that there was some decrease in the overall stability of the surface on this date.

Laboratory compaction of the synthetic equestrian surface under drops of a 1kg weight showed that the total compaction depth increased significantly at higher temperatures. At low temperatures the wax could have hardened thus the surface could have been more rigid and less likely to move or compact under the dropped weight. Conversely, at higher temperatures the wax could have been at various stages of softening and thus the surface could have been more malleable and more likely to compact.

It would not be possible to attribute the individual surface components to specific changes which occurred to the mechanical properties throughout each competition, because the data which was obtained for this study was related to surface use as opposed to surface construction. In future work an ideal progression of this study would be to test surface components in different ratios in order to determine an "ideal" mix in which collectively the components enhanced the surface properties which have been discussed. An additional progression of the research would be to determine how the changes affected the horse, either in terms of performance, or in terms of the risk of injury. Such factors could be linked to the changes which occurred within the mechanical properties (Figure 6.2.1) and therefore merit further discussion.

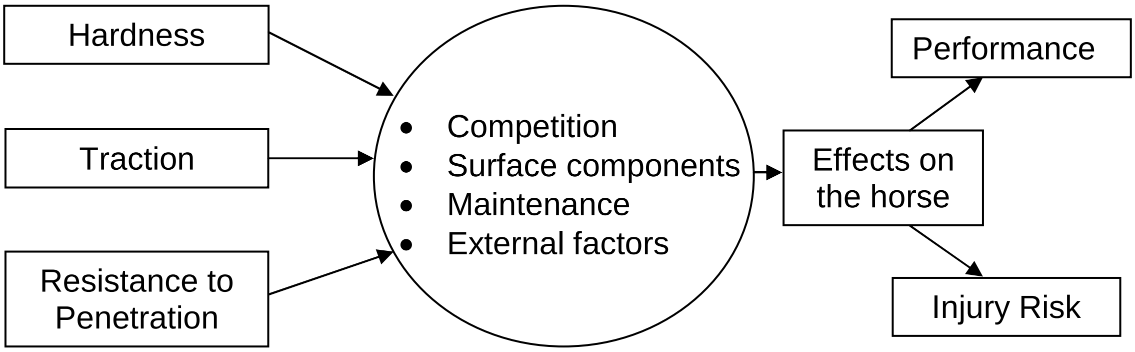


Figure 6.2.1 – The overall picture of the entire study, the mechanical properties were affected by a range of factors, which could have had an effect upon the horse

6.3 The Effects of Mechanical Surface Properties on the Horse

The hardness of the surface was affected by the amount of compaction which occurred under the weight and movement of the horses during each of the dressage competitions. It was determined that the surface became harder throughout each competition, in particular in the central areas of the arena. The hardness of the surface affects the peak loading on the equine limbs and therefore is directly linked to the concussive forces exerted on the limbs and the likelihood of injury as Tessutti *et al.* (2010) described in humans. Pinnington and Dawson (2001) described the motion of human athletes running on soft and hard beach sand. The study reported that on hard, compact sand the total contact area of the foot is smaller than when running on soft, uncompacted sand, and therefore the concussive force experienced is greater on a hard surface compared to a soft surface. This description could be applied when a hoof comes into contact with a surface which is sand-based and hard, the total contact area beneath the hoof would be smaller than if the hoof was to contact a surface which was soft. The hoof would be less likely to penetrate the harder surface, and therefore there would be a greater peak load generated, and more concussive effects on the limbs. Cheney *et al.* (1973) described this effect in terms of the amount of energy which is absorbed by the surface. Impact forces may be reduced by up to 60% by enhancing the energy absorbing properties of the surface. This may be done by ensuring that there is a top layer of approximately 5cm of loose, soft surface (Cheney *et al.,* 1973), but may also be achieved by using a layer of woodchip, as described by Barrey *et al.* (1991). In order to determine the likely effects of the increased hardness on the competitors, it would be necessary to determine the peak loading of the limbs on surfaces with different levels of hardness. Chateau *et al.* (2009b) developed a dynamometric horse shoe on surfaces of different materials, asphalt, grass and sand, and therefore with different mechanical properties. The same study found that the dynamometric horseshoe was a reliable method of measuring ground reaction forces of horses in the walk and trot, on the range of surfaces. It would be useful to use this piece of equipment on the synthetic surface, prepared to different levels of hardness, in order to determine if there is a significant difference between the ground reaction force experienced by the horse on each surface preparation.

One of the primary concerns in arena construction is that the top layer of a surface reduces the impact on the limbs by up to 60% by absorbing the energy of the movement (Cheney *et al.,* 1973). Conversely though, diminished energy return from a track could affect performance to some degree. Cheney *et al.*

(1973) and Peterson *et al*. (2008) both suggested that softer, more penetrable tracks returned less energy than harder tracks and the resulting speed of a galloping horse was slower. Murray *et al.* (2010) suggested that this could cause an increase in heart rate and lead to the horse fatiguing more quickly. To make a comparison to a horse used in dressage, a smaller amount of energy returned from a softer track could affect the biomechanics of movements being performed. This could however be rectified by the inclusion of amendments such as rubber which have an elastic effect. Buchner *et al.* (1994) suggested that horses tested on a soft surface with rubber inclusions exhibited a greater stride length and longer swing duration than those tested on a hard surface, both of which would be positive attributes in a dressage competition.

Chivers and Aldous, (2003) conducted a study into the traction levels of Australian rules football pitches, and found that the traction measurement of the pitch had to be above 35Nm in order to effectively minimise the risk of a slip, and the resultant injury. Equally though, the same paper suggested that it would be important to determine the upper limit for traction since excessive traction properties of a surface may lead to other injuries, in particular knee injuries caused by concussion on the joint. McClinchey *et al.* (2004) suggested that in order for the horse’s weight to be carried effectively and to reduce concussive forces on the limbs there must be some slip of the hoof wall as it contacts the surface. It occurs during the weight-bearing stance phase when the weight of the horse is transmitted as a vertical force through the hoof, and so hoof deformation occurs. A surface with excessive traction would prevent the hoof from slipping and therefore could cause concussive injury to joints. Equally as important and in agreement with the human study by Chivers and Aldous (2003), a surface with too little traction and excessive slip could cause soft tissue injuries due to hyperextension.

Murray *et al.* (2010) and Riggs (2010) have both suggested that surface maintenance and intensity of surface use are key factors in relation to the prevalence of injuries. Preparation of a synthetic surface to a standard based upon the results of mechanical tests would be an ideal method of minimising the risks to injury and performance which have been outlined. The synthetic equestrian surface in this study had been laid for approximately 16 months prior to the onset of the study. Discussions with the arena personnel revealed that the surface was prepared daily using a grader, to the specification of the surface supplier, and was maintained, when the schedule allowed, throughout competitions. Analysis of the arena records showed that there was no significant effect of the intensity of arena use, between competitions, on the initial measurements of the mechanical properties taken at each data collection. There were however significant changes in the mechanical properties of the surface from January 21st to June 24th, suggesting that the current maintenance protocol was not sufficient to maintain a consistent surface in the long term.

There was a single day on which the results did not fall into the same pattern as other results, particularly the hardness and the penetrability results. This was the single occasion on which the surface was prepared, prior to the dressage competition and all testing, by different personnel compared to the other five dates, which indicates that the preparation of the surface may have affected the mechanical properties. In particular, the personnel appeared to rush the grading process, suggesting that the surface could have been significantly compacted before the competition had started, and was then displaced throughout competition. This result highlights a limitation of this study and any study using a commercial equestrian arena; the control of the preparation of the surface. The result does however highlight the importance of surface preparation on the mechanical properties of the synthetic surface. A maintenance protocol may be in place for a surface, but may be interpreted differently by different people, thus the surface may not always be prepared in the same way. In order to overcome this issue it may be useful for surface suppliers to provide training for arena personnel so that the surface can be maintained to the correct standard.

When the synthetic surface was analysed in terms of the depth achieved with each drop of the penetrometer, it was found that the greatest depth was achieved with the first drop of the one kilogram weight and the least depth was achieved with the final drop of the weight. These differences were found to be significant. The results suggest that the topmost layer of the surface, between 1-1.5cm depth, was significantly softer than the layers beneath. Similar effects have been noted in soils which are subjected to heavy farm traffic, in which subsoils became compacted and were more resistant to penetration by plant roots (Saffih-Hdadi *et al.,* 2009). The results from the study suggest that heavy use by horses, over the 16 months since the surface was laid could have caused compaction of the sand in the sub-layers. The results also suggest that preparation of the arena using the grading equipment was limited to the first 1-1.5cm of the surface, and had little effect on the surface below. In order to accurately determine how much the surface had compacted in the sub-layers, it would be necessary to take core samples though, since it is not easy to quantify this using just a Longchamp penetrometer. In addition it is important to take into account the dissipation of the surface to the edges of the arena and the loss of the surface which had compacted in horse's feet and rider's boots. Observations throughout the data collections indicated that heavy use caused the surface to dissipate towards the edges of the arena and therefore it required moving by arena personnel. The loss of the surface over time would also have affected the total depth of the surface within the arena, and left the compacted sub-layers more exposed. This therefore raises questions as to whether the surface preparation was adequate for this synthetic equestrian surface. This information could be used to develop long-term maintenance protocols which may include topping up and re-treating a surface in an arena periodically. This too could be developed based upon the results from regular mechanical testing of the surface.

The starting point for the study of equestrian surfaces at Myerscough College was the 2004 Olympic Games when it was suggested that the injuries of four jumping horses were linked to the arena surface (FEI, 2004). The mechanical properties of the synthetic surface which were measured throughout the study may each be attributable to the likelihood of an injury occurring. A main priority in future research should be to determine the "ideal" level for each mechanical property. By completing this analysis, in conjunction with kinematic analysis of the horse, the changes in the mechanical properties can be plotted against changes in the horse's movement and therefore be used to determine the ideal level for each mechanical property. In doing so, a protocol can be designed to develop an ideal synthetic surface according to discipline. In addition training can be provided to aid arena personnel in the preparation and maintenance of a synthetic surface, and therefore reduce the likelihood of an injury occurring due to the surface.

7.0 Conclusion

The study had two aims, firstly to validate a suite of tests that could be used to quantify the mechanical properties of sand, fibre, rubber and wax equestrian surface. The second aim was to use that suite of tests to determine the effects of preliminary, unaffiliated dressage competitions on the mechanical properties of the same surface. The initial stages of the study found that specific variations of the Clegg hammer, traction apparatus and Longchamp penetrometer were all effective in measuring the mechanical properties of the surface when it had been prepared. The Longchamp penetrometer was less accurate when used to measure a used surface, since the surface itself was uneven, and also because the needle was more likely to be prevented from movement by the fibres within the surface. The results highlight the importance of validating equipment on a surface prior to commencing a major study, and ensuring that the most appropriate method of use is chosen for a specific surface.

The main study found that the surface became harder and more compact as the angular sand grains within the surface were forced closer together under the imposed stress of the horses' weight. The traction of the surface increased as it became harder since there was less space between the sand grains and therefore the grains were more likely to shear against one another. The changes which were reported were not uniform throughout the arena, and the study showed that there were significant differences between the track and central areas, leading to the question of how the pace of the horse affected the changes within the surface. These results suggest that future studies could focus on how each pace affects a prepared surface, and where the most significant changes occur. In addition it would be useful to determine whether the changes which were noted had a significant effect on the horse, by using kinematic analysis.

There were other factors to consider throughout the analysis such as daily temperature, surface use and surface maintenance, however these factors alone could not have produced the results which were obtained. It is important that each of the factors are investigated further to determine the significance of any effect on the mechanical properties of the surface, and therefore obtain a much clearer overall picture of the surface.

Overall, this study has found that measuring the mechanical properties of a sand, fibre, rubber and wax equestrian surface is a valid method of determining how the surface changes, both in the short term, throughout a competition, but also in the long term, over a period of six months. The main implication of this work on the industry is to highlight the importance of developing specific surface maintenance protocols, which in the future could be informed by simple mechanical testing. In doing so, industry personnel could ensure that a surface is consistent and therefore reduce the likelihood of injury.

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REFERENCE NO. ______________

Application for Ethics Approval

APPLICATION TO MYERSCOUGH ETHICS COMMITTEE FOR APPROVAL OF RESEARCH PROJECT

This form should be completed for all **NEW** applications for College Research support and will submitted to the Chair of the Appropriate University Committees if requested.

Does project require a Home Office Licence? NO Project Licence no:_________

Is there a licence holder? YES/NO Who holds it__________ Personal Licence no: _________

Date:

Title of Project:

The Effects of Competition on the Physical Properties of an Equine Arena Surface

Name of researcher and co-workers:

Emma Blundell	
Alison Northrop	
Andrew Owen	

1. Aims and objectives of project: (Layperson's terms).

The aims of the research are to quantify the effects of competition on a sand, fibre and wax, equine arena surface. The objectives are to measure the physical properties of the surface throughout competition and then compare the results of this to an 'ideal' surface.

2. In layperson's terms explain precisely what will happen to them (e.g. killed for Langendorf; tissues collected from abattoir and analysed for zymogen etc):

The study does not directly involve horses. Horses will be ridden on the surface by private owners/riders in a pre-organised, British Dressage (BD), competition.

Rider's are expected to adhere to all BD rules with regards to the welfare of their own horse during competition.

Researcher's will have no direct contact with the horses and no horses will be present in the arena when measurements are being taken.

3a. How many, and which species of animals are intended to be used in the first year? N/A

3b. Where more than one species is used, how many of each are to be used
N/A

4. What is the balance between the cost to the animals involved and the likely benefits to be gained by the research?

In the Athens 2004 Olympics four jumping horses sustained severe tendon injuries which were thought to be related to the footing of the arena surface, it is therefore vital that research into arena surfaces takes place. In the future it may be possible to develop a set of standards for equine arena surfaces – at present this is not available.

5. Are there ways in which the procedures could be refined to reduce the cost to animals without affecting the scientific validity of the project?

The British Dressage is strictly governed and rider's will be expected to adhere strictly to British Dressage rules at all times to ensure the highest welfare standards for horses.

6. Indicate what scope exists for reduction in the number of animals used and refinement in technique as the project progresses.

The number of animals connected to the study is purely dependent on the number of entrants into the British Dressage competition.

7. State any additional reasons that support this proposed use of animals to obtain the specific objectives. Is the number of animals you propose to use appropriate? – i.e. large enough to produce a satisfactory valid result and not greater, in accordance with the principles of Reduction, Refinement and Replacement.

N/A

MYERSCOUGH COLLEGE

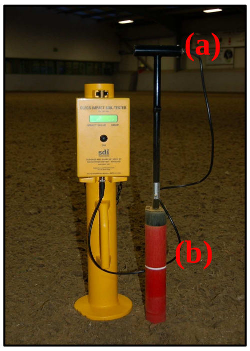
RISK ASSESSMENT TITLE	**PROGRAMME AREA**	**ASSESSMENT UNDERTAKEN**	**ASSESSMENT REVIEW**
The Effects of Competition on the Physical Properties of an Equine Arena Surface	**MSc (by research)**	**Signed:** ____________________ **Date: 3/5/2008**	**Date:** ____________________

STEP ONE	**STEP TWO**	**STEP THREE**
Risk of back injury when moving equipment or injury if equipment is dropped	Researcher and co-workers	Ensure correct protocol is followed for the lifting and moving of loads. All heavy items (traction equipment) must be carried between two people
Risk of injury to hands when carrying traction equipment	Researcher and co-workers	Ensure protective gloves are worn when carrying traction equipment and carry the equipment between two people.
Risk of injury when using laboratory equipment for example when mechanically sieving the surface	Researcher and co-workers	Ensure correct laboratory procedures are followed at all times and wear protective clothing such as goggles, gloves and laboratory coat. Ensure protective gloves are always worn when using the ovens.

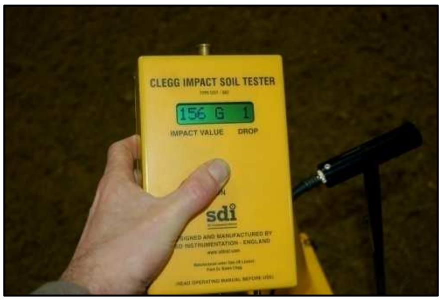
Risk of burns when using drying ovens Risk of injury due to spooked horse Risk of contamination of other things handled after handling the surface Risk of slipping when exiting the arena due to a build-up of the surface on the soles of shoes	Researcher and co-workers Researcher, co-workers, all arena personnel, competitors, spectators, horses in the arena Researcher and co-workers Researchers and co-workers	Ensure the arena is empty before using the equipment, if a horse does become loose or enters the arena cease work immediately and ensure the research, co-workers and equipment remain in a place of safety. Always wash hands after handling the surface and the equipment. Clean shoes before exiting the arena by knocking any build-up of surface off the soles.

Section A – Guide to Using a 2.25kg Clegg Impact Tester

1. Stand the Clegg Impact Tester upright on the surface. A foot can be placed on the base of the equipment in order to hold it steady on the surface.



2. Lift the 2.25kg weight up by the handle (a), to the level of the weight line (b) marked on the weight.



3. Unhook the digital display meter from the guide tube. Press and hold the “ON” button and drop the weight. Record the reading BEFORE releasing the button.

Section B – Guide to Using a Torque Wrench

1. Drop the torque wrench from a height of 0.2m, ensuring that lifting protocol is followed (bend knees, and push up, do not strain the back).
2. Turn the handle clockwise with the right hand, while supporting the other end of the handle, lightly, with the left hand. Keep turning the handle until the surface displaces

3. The blue needle will move the silver needle. Read the scale where the silver needle stops moving.

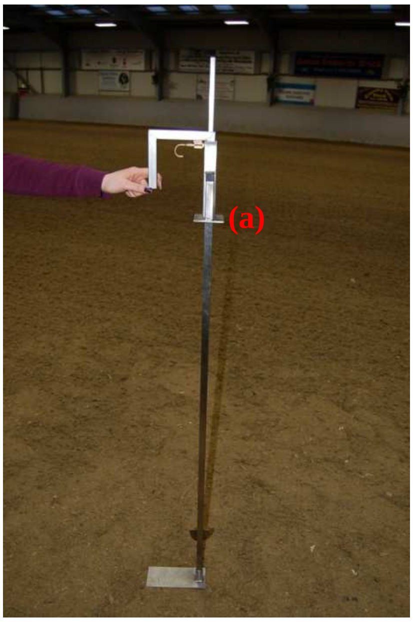
Section C – Guide to Using a Proctor Penetrometer

1. Rest the tip of the needle of the penetrometer on the top of the surface.

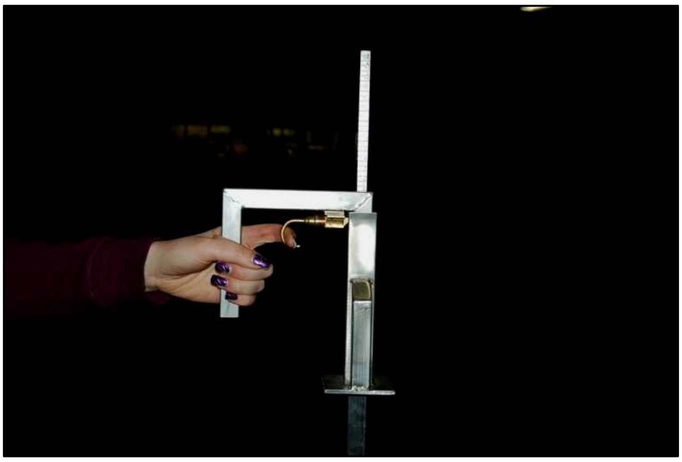
2. Apply pressure to the handles until the needle penetrates the surface approximately three centimetres. This level can be marked on the needle using tap e (a).

3. A ring will move up the stem of the handle, along the scale. Read the scale from the top of the ring.

Section D – Guide to Using a Longchamp Penetrometer



1. Ensure the penetrometer is stood level on top of the surface, and the scale reads zero.
2. Lift the weight to the top of the one metre stem, so that it locks into place (a).



3. Pull the trigger to release the weight, which will then fall one metre onto a 1cm² needle.

4. Read the scale at the top of the penetrometer in the same style as an ordinary centimetre incremented ruler.
5. BEFORE moving the penetrometer repeat steps 1-4 a second and a third time in order to get a set of three readings for each area.

Table 4A shows the mean and the standard deviation of each set of results obtained from the Longchamp and Proctor penetrometer. These figures were used to determine the coefficient of variance for each piece of equipment during the validation (Chapter 2).

	Proctor Penetrometer		**Longchamp Penetrometer**	
	Mean (lbf)	**Standard Deviation**	**Mean (cm)**	**Standard Deviation**
1	39.5	1.4	2.0	0.5
2	39.2	2.0	2.3	0.2
3	43.6	1.6	2.0	0.6
4	44.8	1.9	2.1	0.5

Table 5A shows the mean values of traction obtained from eight different researchers in one area of a sand, fibre, rubber and wax equestrian surface which had been graded using equipment provided by the same company that laid the surface. When analysed using one-way ANOVA it was found that there was a significant effect of researcher (P<0.001) on the results. This suggests that only a single researcher should have used the equipment throughout data collections. Unfortunately this highlights a limitation in the results since different researchers used the equipment for the first three data collections.

Table 5A – Mean traction values obtained on a sand, fibre, rubber and wax equestrian surface, by eight individual researchers

Researcher	Mean Traction (Nm)
1	20
2	16***
3	19
4	20
5	20
6	18***
7	19
8	19