The Effect of Two Maintenance Procedures on an Equine Arena Surface in Relation to Motion of the Hoof and Metacarpophalangeal Joint

by

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Abstract

Maintenance procedures are reported to affect surface properties. The majority of work regarding surfaces in relation to performance and welfare is currently race track specific. The study aimed to investigate limb and hoof movement on a synthetic arena surface following two different commonly used preparations (harrowing and rolling).

Nine horses were recorded using infrared cameras and retro-reflective markers, in walk, trot and canter, on two surface preparations in a cross-over design. Hoof range of motion (ROM) and displacement as well as metacarpophalangeal joint (MCPJ) extension and third metacarpal (MCIII) inclination were analysed using ANOVA. Surface hardness and traction were also measured. Speed was monitored using a marker on the sternum.

No difference was found between maintenance treatments for speed, hoof ROM or hoof displacement. Results showed significantly greater ($P<.05$) MCPJ extension at mid-stance following harrowing and significantly ($P<.05$) greater MCIII adduction at impact following harrowing, when gait was grouped. Hardness and traction were statistically similar on both treatments.

Alterations to the surface cushion that do not significantly alter hardness and traction appear to be sufficient to produce subtle changes in stride characteristics. The difference in MCIII adduction shows that foot placement in the frontal plane changed, but the support that the surface gave the hoof did not. Greater MCPJ extension on the harrowed surface was unexpected and *post hoc* analysis identified that the position of the sternum marker relative to the planted foot was further ahead at mid-stance. A greater percentage of bodyweight on the forelimbs would produce greater extension.

Table of Contents

List of Plates

List of Figures

List of Tables

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Chapter One - Literature Review.

1.0 Introduction - The use of synthetic surfaces for equine exercise, training and competition is rapidly growing (Murray *et al.,* 2010a). Mechanical surface properties do however affect the limb loading rates, shock attenuation and supporting structure loads, as well as the accelerations and decelerations of the limb and hoof (Gustås *et al.,* 2006a; Hobbs *et al.,* 2010). The relationships between manmade surfaces, welfare and performance therefore warrant further consideration (Reiser *et al.,* 2000; van Weeren, 2010).

In the field of human sports, the governing bodies have made improvements in the surface substrate and maintenance techniques used in regard to optimising performance and minimising injury risk (Murray *et al.,* 2010a; Swan *et al.,* 2009). Testing procedures and strict building and maintenance guidelines of training and competition surfaces have allowed human sports to work towards an achievable end goal, however currently the same cannot be said for the equine industry. There are at present no set standards or regulations governing surfaces in relation to type or maintenance procedures necessary to maintain the optimum health and wellbeing of the horse (Weishaupt, 2010a; Wheeler, 2006). The reason for this deficit can be attributed to the fact that not enough is known concerning a surface and its relationship to the kinetics and kinematics of the horse. Researchers within the industry are working towards a greater understanding of the effect a surface will have on the movement of the horse to be able to provide greater welfare and improved performance (Chateau *et al.,* 2010; Gustås *et al.,* 2006a; Hobbs *et al.,* 2010; Murray *et al.,* 2010a; Peterson *et al.,* 2011; Ratzlaff *et al.,* 2005; Setterbo *et al.,* 2011; Weishaupt, 2010a).

Research regarding horse and ground interaction has until recently focused mainly on racehorses and therefore race tracks (Burn and Usmar, 2005; Dallap-Schaer *et al.,* 2006; Peterson and McIlwraith, 2008; Ratzlaff *et al.,* 2005). It should be noted however that even within a single discipline, considerations are not necessarily simplified. Parkin *et al.* (2004a) observes that what may prove best for one type of racing may not for another. The surface requirements for a national hunt horse, for example, are not the same for a horse running on the flat due to factors such as difference in age, height, weight, speed of race and forces encountered on turns and jumps between the two different race types (van Weeren, 2010). Epidemiological studies have identified the effect that race type has on injury risk (Mohammed *et al.,* 1991; Parkin *et al.,* 2004a,b,c; Williams *et al.,* 2001).

Extreme concussive forces experienced in fast paced events such as racing are often stated as causal factors for catastrophic breakdown (Crevier-Denoix *et al.,* 2009; Drevemo and Hjerten, 1991; Williams *et al.,* 2001). It is important to recognise however that the racehorse's career is relatively short in comparison to those in other disciplines. Dressage horses suffer much less high impact, speed related concussion but have much longer careers than those racing. High strains and compression of joints over long periods of time result in chronic degenerative problems such as arthritis of the knee and hock (Murray *et al.,* 2006; Murray *et al.,*2010b). The idea of catering surface type to discipline is fast becoming the consensus (Murray *et al.,* 2010a; Parkin *et al.,* 2004a; van Weeren, 2010) meaning further discipline specific research into surface substrate and maintenance is needed.

The optimum surface for any given discipline is yet to be agreed but has been described by Barrey *et al.* (1991) as needing to minimise concussion through energy absorption, whilst still returning suitable power to aid performance. The ideal surface to gallop a two year old race horse on will not be the ideal surface to jump a 15 year old top level eventer. As horses age, the body absorbs and handles loads and impacts differently (van Weeren, 2010). The musculoskeletal system of a young horse can adapt in relation to the extent and intensity of training it receives (Butcher and Ashley-Ross, 2002). The stiffness of the suspensory apparatus of the metacarpophalangeal joint (MCPJ) however has been found to increase in relation to age and not training (Butcher and Ashley-Ross, 2002). Stiffness of such structures is needed to avoid over extension of certain joints but not all natural changes are as beneficial for the horse. Stiffness can continue to increase as the horse ages and will detrimentally affect mobility. Additional age related degenerative changes, such as osteoarthritis for example, have been epidemiologically reported in highly mobile joints in domesticated as well as wild horses (Butcher and Ashley-Ross, 2002; Cantley *et al.,* 1999). Taking age related changes of the equine athlete into account is yet another challenge researchers face when searching for a uniformly ideal surface.

Weishaupt (2010a) states that the need for objective information is a necessity if the industry is to move forward. Individual pieces of work go a small way to answering a much larger question and retro-respective studies, such as epidemiological ones, can only provide limited information. Anecdotal evidence of surface characteristics, related to injury and substandard performance, needs to be replaced with thorough investigatory work that provides qualitative but also quantitative information (Peterson and McIlwraith, 2008; van

Weeren, 2010). Future research should incorporate substrate characteristics, measured using a reliable and repeatable system, with kinematic or kinetic data of the horse.

1.1 The interaction between the horse and the surface

1.1.1 The movement of the horse Horses use different gaits consisting of varying footfall patterns and speeds. Throughout all of the gaits the forelimb swings in a way similar to a pendulum with the muscles of the scapula and humerus moving the proximal limb whilst the segments of the distal limb follow inertly (Back *et al.,* 1995). A single stride is divided into two parts known as stance and swing (Clayton, 2002) with the stance phase describing the time in which the limb is in contact with the ground and the swing when the limb is airborne. In more recent work the stance phase itself has been divided into four stages; primary impact, secondary impact, support and break over (Thomason and Peterson, 2008; Peterson *et al.,* 2011).

1.1.2 Primary and secondary impact The impact stages of the stride involve the hoof contacting the surface, with vertical and horizontal landing and breaking forces occurring (Back, 2001). The scale of the forces encountered will depend on a number of factors but the mechanical property of the surface is strongly implicated (Peterson *et al.,* 2011). In relation to a synthetic substrate, opposed to turf or tarmac for example, it is the top layer of the surface that works to initially decelerate the hoof as it undergoes compression (Peterson *et al.,* 2008). The hoof works to dampen the shock, meaning that with a suitable top surface layer, the forces produced should be within the safe manageable limits of the limb. In the faster gaits such as gallop it has been suggested by Peterson *et al.* (2008) that the vertical velocity of the hoof at this point could possibly be in the region of $8ms^{-1}$. The time that the limb has to absorb ground reaction forces (GRFs) is greatly reduced due to the shorter period spent with the hoof on the ground (Wilson *et al.,* 2001). Large GRFs coupled with shorter times for absorption and attenuation are believed to be the reason the impact stage is often implicated in the development of arthritis amongst other injuries (Back, 2001). Peterson *et al.* (2011) describes the stage where the hoof travels in a downward motion and strikes the ground almost vertically to be the primary stage of impact. As the body of the horse moves forwards after the initial impact, its force causes the hoof to slide forward before stopping again causing an additional collision to the primary impact, which is consequently termed secondary impact (Peterson *et al.,* 2011). GRFs are now seen to increase as the surface produces an equal opposing force to that of the horse (Gustås *et al.,* 2004). GRFs and deceleration of the hoof at impact on differing surfaces have been measured using various techniques including force shoes and plates (Chateau *et al.,* 2009), accelerometers (Burn *et al.,* 1997) and hoof strain gauges (Savelberg *et al.,* 1997). Such studies have in recent years aided researchers to gain a better understanding of the relationship between the horse and the surface at such an important part of the stride.

1.1.3 Support As the horse moves through the stance phase the body travels forward over the limb, which is now acting as a supportive strut (Clayton *et al.,* 2000) and the weight and force is transferred from the loose top layer of a synthetic surface to the stiffer layer directly below (Peterson *et al.,* 2008). It is important to remember that whilst vertical GRFs can reach a peak at midstance of up to two and a half times body weight, there are also horizontal forces at work (Lanovaz *et al.,* 1998; Smith *et al.,* 2002; Witte *et al.,* 2004). The surface's ability to handle this horizontal movement and force is considered in terms of shear strength. The shear strength and impact resistance of a surface are linked to its hardness and directly affect the amount of hoof slip and rotation (Gustås *et al.,* 2006a). A comparatively hard surface with high shear strength causes minimal hoof slip and rotation and therefore rapid deceleration at impact through to mid stance (Gustås *et al.,* 2006a). Such high GRFs can result in tissue concussion and damage to the articular cartilage and supporting structures (Barrey *et al.,* 1991; Ratzlaff *et al.,* 1997) with catastrophic breakdown of bone and tendons more likely to occur at this point compared to other phases of the stride (Peterson *et al.,* 2011). A comparatively soft surface with low shear strength however can cause large amounts of hoof slip and rotation leading to muscle fatigue, which can damage the flexor tendons and ligaments as the horse pushes itself out of the surface and off the ground (Murray *et al.,* 2010a). The amount of shear strength a surface provides is therefore key during this part of the stride (Peterson *et al.,* 2011) and further work in this area is needed to ascertain the optimum values.

1.1.4 Break over and swing The terminal event of stance phase is referred to as toe-off, or break over, which involves the rotation of the heels over the toe disengaging contact with the surface (Eliashar *et al,* 2002). If the surface has low shear strength the hoof is able to rotate forward and this aids the horse in dealing with the change in direction of forces (Peterson *et al.,* 2011). After break over the swing phase occurs, the limb is airborne and the hoof accelerates with the forward momentum of the horse (Peterson *et al.,* 2008). Break over ends with all forces reduced towards zero at toe off (Thomason and Peterson, 2008). It is important that the relationship between break over and the surface is not overlooked as any alteration to break over will directly affect the limb in swing.

<u>1.2 Dynamic ability of the distal limb</u>

<u>1.2.1 Adaptive Hypertrophy</u> The limb will be subjected to dynamic loads during movement which the horse has evolved to absorb and dissipate (Peterson, *et al.,* 2011). Acceptable levels of shock passing through the limb are in fact beneficial to the horse and result in adaptive hypertrophy of the systems, which can help to strengthen the limb (Goodship and Smith, 2004; Marlin and Nankervis, 2002; O'Sullivan and Lumsden, 2004). Bone remodels according to the pressure, frequency and duration of the loads it receives (Rivero *et al.,* 2007; Goodship and Smith, 2004). It is made stronger and better suited to specific types of work if training regimes have been identified and implemented correctly (Goodship and Smith, 2004). If such forces however exceed tolerable levels the systems move beyond adaptive hypertrophy and injury occurs either via catastrophic breakdown or degenerative changes (Peterson, *et al.,* 2011). The forces sustained by the horse during movement and subsequent levels of adaptation to them are influenced by exercise intensity and the relationship of the limb with the surface.

<u>1.2.2 Foot bearing</u> Limb impact and hoof deceleration are directly influenced by surface-hoof interaction (Crevier-Denoix *et al.,* 2009; Johnston and Back, 2006). Chateau *et al.* (2010) identified that the amount of shock the limb is subjected to during movement is directly dependant on the nature of the two objects that collide. The hoof tends to land asymmetrically with the lateral side landing first followed by a medial rocking motion until the hoof then becomes stabilised during the support stage (Chateau *et al.,* 2005; Chateau *et al.,* 2006a; Johnston and Back, 2006). Initially the heel sinks during the impact stage, followed by forward toe rotation from mid-stance through to break over when working on compliant surfaces (Chateau *et al.,* 2005; Johnston and Back, 2006). Heel first landing such as this has also been reported in feral as well as sound domestic horses (Trotter, 2004) with foot conformation, shoeing and track surface being the direct modifier of loads applied to the hoof and therefore the limb (Johston and Back, 2006).

As well as rotation the hoof undergoes a certain amount of slippage, also known as displacement, in the first milliseconds of the stance phase (Merkens *et al.,* 1993; McClinchey *et al.*, 2004). It is known to be beneficial for a certain amount of displacement to occur as it increases hoof deceleration time resulting in a more gradual loading of the limb. The level of slip that occurs can however vary greatly due to factors such as velocity, shoeing and surface substrate characteristics (McClinchey *et al.,* 2004; Orlande, 2009).

Movement in the distal limb is mainly restricted to flexion and extension. It is the collateral ligaments, the presence of the sagittal ridge and the shape of the joint surfaces which aid in limiting abduction and adduction of the limb when the structure is loaded (Heaps *et al.,* 2011). Normal low levels of axial rotation and collateromotion seen in the distal interphalangeal joints are increased by asymmetric placement of the foot on uneven surfaces (Chateau *et al.,* 2001). Displacement or incorrect rotation of the hoof during the stance phase of the gait has been reported to be a common cause of injury to the supporting structures of distal limb joints (Chateau *et al.,* 2001; Clanton *et al.,* 1991; Heaps *et al.,* 2011). Hoof displacement during impact at gallop has been implicated in the aetiology of soft tissue injury in the racing Thoroughbred (Clanton *et al.,* 1991). It is suggested therefore that although certain levels of hoof displacement and rotation can benefit the horse there is a point at which it can become damaging. It is also important to note that optimal levels for both factors are yet to be agreed on and reported. The effect the surface has on foot bearing and movement of the structures of the distal limb is considered to be one of the most important factors in the occurrence of injury (Chateau *et al.,* 2010; Heaps *et al.,*2011; Salo *et al.,* 2009; Weishaupt, 2010a). Analysing the effect of alterations in surface mechanical properties on the motion of the hoof could be of great value in regard to improving welfare of competition and leisure horses. Incorrect placement or rotation of the hoof will place extra forces on the limb, especially at the highly mobile joints such as the MCPJ. The surface substrate and its preparation is therefore a priority for further research in this area.

1.2.3 The metacarpophalangeal joint (MCPJ) The MCPJ of the equine distal limb comprises of a number of bones and supporting structures (Butcher and Ashley-Ross, 2002). The third metacarpal, proximal phalanx and the proximal sesamoids are supported by the distal sesamoidean ligament, suspensory ligament (SL) and the deep digital flexor tendon (DDFT) (Smith *et al.,* 2002). The support created by these structures enables the joint to resist extension caused by GRFs. Extension of the MCPJ has been described as being a passive event caused by the vertical forces placed upon it (Johnston and Back, 2006). A large increase in horizontal breaking force and vertical ground reaction force is transmitted through the limb during stance (Johnston and Back, 2006). Extension of the MCPJ is at this point resisted by the superficial digital flexor tendon (SDFT), DDFT and the SL (Clayton *et* *al.,* 1999; McGuigan and Wilson, 2003; Smith *et al.,* 2002). The SL however has no muscular component or crimp fibres, like those found in the tendons, to aid in adjusting tension. Strain in the SL is therefore completely dependent on the angle of the MCP joint, with maximal values reached during mid-stance due to high weight bearing (Clayton, 1997). Dressage horses, during highly collected movements, have been reported to be at a greater risk of injury of the SL in the hind limbs than in any other type of discipline (Murray *et al.,* 2006. It should be noted, however, that eventers and show jumpers are also prone to this type of injury (Murray *et al.,* 2006).

A single catastrophic event can cause breakdown of the horse during locomotion, however injuries are more frequently caused by repeated trauma sustained during training and competition (Clayton, 1997). Age related changes such as osteoarthritis of the joint cartilage have been found to increase in severity through biomechanical loading (Radin, 1983). The MCPJ has been reported to show the highest number of degenerative and traumatic lesions of any appendicular skeletal joint (Brommer *et al.,* 2003). Pool (1996) attributes damage such as this to a small surface area combined with a large range of motion and increased loading at certain points of the stride. The bones and supporting structures are affected by cyclical loading rates which are determined by intensity, combined with factors related to ground surface substrate (Clayton, 1997; Heaps *et al.,* 2011; Smith *et al.,* 2002).

The MCPJ is functionally specialised to move mainly in the sagittal plane (Chateau *et al.,* 2001) though it is not limited to this direction, as has been reported by Butcher and Ashley-Ross (2002). A number of researchers (Chateau *et al.,* 2001; Clayton *et al.,* 2007; Heaps *et al.,* 2011) concluded that passive abduction and adduction and some axial rotation were the likely cause of injury in the joint. Chateau *et al.* (2001) demonstrated that small amplitude movements in the MCPJ are found outside the sagittal plane when moving on an even surface. Work over irregular surfaces causing an uneven bearing of the foot was then shown by Chateau *et al.* (2002) to significantly affect the angle of collatermotion in the joint, as well as the amount of axial rotation. The supporting structures and bones are therefore subjected to high peak forces, concussions and strains on uneven ground, meaning that breakdown and consequent injury often occur (McGuigan and Wilson, 2003; Smith *et al.,*2002).

1.3 Arena characteristics

1.3.1 Surfaces The different constituents of surfaces will all have an effect on the motion of the horse and therefore the forces applied to the limb. In turn the horse will affect the surface and can, over time, change its hardness and stability. de Lagarde and Betsch (2008) suggest the quality of a track is related to factors such as its substrate composition, the type and frequency of maintenance it receives as well as daily factors, which include the number of horses running, the training time and the local temperature and humidity. The primary quantitative measures for substrate composition are often reported in terms of particle type, size and distribution, organic content and moisture content (Peterson *et al.,* 2008). Peterson *et al.* (2008) states however that as there is currently no suggested range for such measurements, the relationship between them and biomechanical characteristics is still not fully understood.

1.3.2 Substrate materials Considerations for the substrate laid on any race track or arena include product cost, availability of materials, expected workload, ambient temperature, rainfall and humidity and often the individual or group's preference. Peterson *et al.* (2011) suggest that the race track designer's experience will greatly affect the choices made regarding cushion and base type. Chateau *et al.* (2010) reports that in the case of racehorses it is the trainer that selects the surface type most often used, both Peterson *et al.* (2011) and Chateau *et al.* (2010) however report that choices are generally made with no scientific substantiation. Research into the characteristics of a variety of substrates is subsequently carried out to understand better the effect such choices will have on the horse, in both the short and long term.

1.3.3 Woodchip There is a variety of materials currently available for equine arena surfaces. Wood chip, once extensively used due to its price and availability went through a decline in popularity in favour of other substrates. The current economic climate alongside environmental considerations has however caused woodchip to be reassessed as a possible substrate of choice. A recent study by Murray *et al.* (2010a) concluded that using woodchip can result in sliding in cold or wet weather conditions, particularly after a jump. Previous to this Drevemo and Hjerten (1991) have reported high decomposition rates and management problems making its comparatively low price less attractive over time. A study by Barrey *et al.* (1991) however did report that of the dirt racetracks the researchers tested, the most efficient at structural dampening proved to be the track with added woodchip. Barrey *et al.* (1991) found a reduction in the hoof's peak deceleration rate and vibration, which was later supported by a study by Ratzlaff *et al.* (1997). Ratzlaff *et al.*

(1997) found that a high percentage of organic material in the substrate coupled with low compaction of the surface resulted in reduced impact forces. It is important to note however that Barrey *et al.* (1991) reported that newer substrates of the time such as leather chips or rubber showed similar properties to the woodchip but with fewer long term maintenance issues compared to woodchip.

1.3.4 Rubber Rubber has previously been found to alleviate hardness in human sports surfaces as well as helping to lessen substrate wear caused by stress in high-traffic areas (Baker *et al.,* 2001). It is therefore not surprising that in a recent study (Murray *et al.,* 2010a) based on questionnaire results for Dressage riders, approximately half of all the respondents currently used an arena composed of a sand and rubber mix. Murray *et al.* (2010a) reported that when rubber was used on top of the sand it helped to keep a uniform top layer but when mixed its ability to do this was reduced and the risk of injury through impaired stability was increased. The authors attribute this to the surface drying due to increased moisture evaporation when the top layer of sand was exposed to the climatic conditions. Such findings support earlier research by Baker *et al.* (2001) that found that too large a ratio of rubber to sand could adversely affect water retention and therefore shear strength causing increased risk of balance loss to the horse. It is important to note though that the results from Murray *et al.* (2010a) were collected via a survey making them subjective in nature. Further work that includes collection of kinematic data in relation to movement of the horse is therefore necessary to fully explore such findings.

1.3.5 Sand Sand, when used for surface material is considered in terms of the size, shape and distribution of its particles. The attributes of these particles affect the moisture content of the surface, porosity and therefore drainage rates as well as the amount of compaction and shear strength (Peterson *et al.,* 2011). The sand used in arenas tends to range from around 0.05mm in diameter to 2.0mm (Wheeler, 2006) and is referred to as fine and coarse sand respectively. Murray *et al.* (2010a) reported that fine sand appeared to reduce the likelihood of tripping compared to coarse sand and was also better at maintaining uniformity in dry conditions. It is important therefore to understand the varying characteristics of the individual grains in order to predict the effect of heavy use during training or competition.

Sand has long been used for exercising horses on but this does not mean that when used alone it is an ideal substrate to improve performance and reduce injury risk. Murray *et al.* (2010a) reports that sand affects propulsion stored as elastic energy in the tendons due to decreased shear resistance, which increases the risk of a trip. A reduction in propulsion is also suggested by the same authors to cause a loss of hoof height during jumping, leading to reduced performance, decreased time to fatigue and increased risk of collision with an obstacle. In conjunction with this a further study by Murray *et al.* (2010b) found that horses that had not previously trained on sand were at a higher risk of injury on sand compared to horses that did so regularly. Information such as this suggests that sudden changes in surface type can result in acute lameness through lack of adaptive conditioning, especially where sand is concerned. It should be noted however that a gradual reduction in risk of lameness was seen when horses were worked consistently on sand, which the authors attributed to bone and tendon conditioning.

1.3.6 Wax - The use of wax in sand surfaces is becoming more popular, especially with indoor arenas as it is thought that the wax helps to retain moisture and therefore reduce dust which can be a problem in covered training areas (Wheeler, 2006). In addition to this an increase in moisture retention leads to a reduction in water application resulting in reduced labour and costs. Murray *et al.* (2010a) identified that wax-coated sand surfaces or a mix of sand and rubber were associated with a lower risk of injury in comparison to sand alone. Findings such as these are further supported by Robin *et al.* (2009) and Crevier-Denoix *et al.* (2009). Robin *et al.* (2009) found the maximum breaking force to be reduced on a waxed surface compared to crushed sand. Crevier-Denoix *et al.* (2009) reported that maximal tendon force was significantly lower in horses worked on an all weather waxed track compared to crushed sand. The change in angles of the distal joint segments was found to be smoother on the waxed surface. Both studies suggest that wax allows for higher deformability of the surface allowing the heels to penetrate the top layer leading to a more progressive loading of the SDFT in the forelimb. It is important to mention however that Robin *et al.* (2009) reported that stride length was shorter on wax, although the speed remained constant, which would suggest reduced efficiency if performance were to stay the same. Work by Bridge *et al.* (2010) and Peterson *et al.* (2010) found that wax was not always stable under varying heat conditions and that on some American race tracks it melted during the day due to changes in temperature. Melting of the wax will inevitably result in an alteration of the mechanical properties of the surface. The study by Peterson *et al.* (2010) identified some of the components of waxes commonly used in surfaces and the effect that temperatures typically recorded on American tracks had on individual melting points. High temperatures like those reported by both studies may not have year round implications concerning surfaces used outdoors in England but such interactions must be considered. Knowledge of the interaction between the wax, sand and other materials such as rubbers and fibres under more temperate conditions would be of benefit to the UK equine industry.

1.3.7 Fibre A number of human studies (Gibbs, 2002; Richards, 1994; Spring and baker, 2006) have found the amending of sports surfaces with polypropylene mesh and fibres to be beneficial in improving surface stability especially during high wear activities. Further to this it has been reported that such fibres can reduce hardness, leading to a possible decrease in injury (Spring and Baker, 2006). A number of chopped fibres are now available for equine surfaces, either pre-mixed with other substrates or sold as an additive to improve an unstable or hard sand surface.

Sand mixed with other substrates such as rubbers, fibres and wax, is becoming progressively more popular in the industry and such a mix is commonly referred to as a synthetic surface. Using a combination of materials can often mean that the component parts behave differently from when they are used alone. Peterson *et al.* (2011) states that the cohesion of the materials will depend on the amount of wax used and that shear properties will be affected by the wax, fibre and rubber content and its interaction with the sand particles.

1.3.8 Moisture content Recent work concerning race tracks by Peterson *et al.* (2011) indicated that the moisture content of the base of a track remains relatively consistent, however the same is not reported for the top cushioning layer. The moisture in the top layer has been found to fluctuate widely in different conditions as well as between different areas of the same race track on the same day (Ratzlaff *et al.,* 1997). Peterson *et al.* (2011) report that compaction of a surface is a function of the material's moisture content, therefore often making for an uneven track. Barrett *et al.* (1997) found dynamic loading in humans to differ substantially between running on a dry sand and wet sand surface. The wet sand showed higher peak impact forces but lower surface penetration values which would suggest that too much moisture can cause higher levels of trauma to the joints but too little moisture is likely to cause propulsion issues and strain injuries. An increase in moisture content of a sand based surface results in increased particle adherence and therefore more resistance to shear movement providing a more stable surface. Finding the ideal moisture content is therefore of importance. Murray *et al.* (2010a) suggests that moisture content of sand surfaces should be approximately 8-12% to give a more stable surface. Barrey *et al.* (1991) stated however that between 8-17% water content aids in the reduction of peak deceleration and vibration in the hoof but on a sand surface the optimum water content depends entirely on the particle size distribution.

1.4 Mechanical surface properties

1.4.1. Hardness A Clegg impact tester is a widely recognised tool used for measuring the hardness of a surface in human and equine sports (Caple *et al.,* 2011; Malmgren, *et al.,* 1994; Popke, 2002; Setterbo *et al.,* 2011). The equipment works by measuring the deceleration on impact of a weighted hammer that is dropped through a hollow tube (Fulwider and Palmer, 2004). An accelerometer is fitted to the hammer and measures the impact and then displays the information in terms of a numerical value (Gravities=G) on a digital display (Mcnitt *et al.,* 2004). The weight of the hammer used as well as the height it is dropped from varies between studies. Baker and Canaway (1993) stated that the values attained for hardness will vary depending on the drop mass and height as well as the area of contact between hammer and surface. Further to this Baker and Canaway (1993) reported that results could show even greater levels of variability than those already recorded between hammer weights when testing a multi-layered surface. Baker *et al.* (2007) reported that a heavier weight, 2.25kg compared to 0.5kg, more accurately represented the hardness of a layered surface due to the increased kinetic energy it gathers before impact. Baker *et al.* (2007) went on to report that heavier weights show less rebound on impact. Equine arenas are designed to generally have a solid hard base underneath a settled pad layer of substrate and finally a lighter top layer of material, providing they are suitably maintained. Findings such as this are important when measuring surfaces which are likely to contain materials prone to elastic deformation such as rubbers and fibres which are often used in equine surfaces. The weight and drop height of the hammer used should therefore be tailored to the specific research work to give accurate measurements. Hardness for equine arena sand substrates have been reported by previous researchers to be between 60 and 100 G (Blundell *et al.,* 2010; Fidler, 2008).

1.4.2 Shear strength The ability of a surface to handle horizontal movement and force is considered in terms of shear strength. The amount of shear strength present in an equestrian surface will greatly affect hoof slip and rotation during the stance phase of the gait (Gustås *et al.,* 2006a). Comparatively high or low amounts of shear strength increase possible injury risk. Ideally the surface should allow the horse sufficient grip to avoid excess slipping whilst also allowing some amount of movement to prevent concussive limb injuries (McClinchey *et al.,* 2004).

Torque wrenches have been successfully used to measure the level of torque, as an indicator of shear strength, on recreational sports surfaces used by humans. (Spring and Baker, 2006). The torque wrench uses a weighted disk to measure the amount of force required to turn the apparatus against a given surface. Measurements are taken by dropping the wrench from a height of 0.2m and then applying force to turn the handle. The dial on the apparatus gives a numerical value in Newton meters (Nm) of the amount of force that is required to produce a turning motion of the base plate against the surface. In human sports such as Australian Rules football, the disk has been adapted with studs to mimic the players' footwear (Chivers and Aldous, 2003). In equestrian sports, research has been conducted to validate use of a disc designed to replicate a shod hoof (Blundell *et al.,* 2010; Fidler*,* 2008). Blundell *et al.* (2010) reported there to be significant associations between the various weights available for use on the torque wrench and the result given. The researchers concluded that the 30Kg weight provided the most appropriate results when used on equestrian surfaces as it showed the lowest sample variance. Findings such as those by Blundell *et al.* (2010) suggest that an equine specific plate with a 30Kg weight would therefore provide reliable shear strength data for an equine surface especially for comparative work due to the low sample variance.

1.4.3 Surface maintenance Peterson *et al.* (2011) states that, although it is the surface substrate that is most commonly considered when looking at mechanical properties, much of the performance of substrates is dependent on maintenance. Currently there are no set standards for arena surface maintenance in competition (Wheeler, 2006) meaning that manufacturer guidelines and past experience are used to prepare the surface (Chateau *et al.,* 2010). It is well reported that harder surfaces are associated with increased risk of fatal injury in racing (Dallap Schaer *et al.,* 2006; Parkin *et al.,* 2004a,b,c; Peterson *et al.,* 2011; Williams *et al.,* 2001). Incorrect maintenance technique and overuse can cause even a high class surface to become hardened over time thus losing the ability to absorb and return energy in sufficient measures often resulting in concussive injuries. Parkin *et al.* (2004) describes hardness as potentially modifiable with use of correct maintenance, making it one of the most important considerations when trying to create the optimum surface.

1.4.4 Maintenance research It has been suggested that dressage horses trained on livery yards or shared arenas were at higher risk of lameness over a two year period than those trained on privately owned surfaces (Murray *et al.,* 2010b). Information such as this suggests a link between the number of horses using the surface compared to the amount of arena maintenance. Heavier footfall and lower maintenance levels lead to a change in the mechanical properties of a substrate and depending on environmental conditions certain areas of the surface are likely to become either deeper or thinner or hold more water. All of these conditions would cause disruption to the biomechanics of the horse.

Information regarding the correct type and amount of maintenance each substrate needs to produce a consistent surface is therefore a high priority. Parkin *et al.* (2004a) highlights that an uneven track surface alters the balances of forces through the hoof and therefore the limb. Kai *et al.* (1999) reports that the magnitude of forces exerted on the hoof and limb vary greatly with each stride as a consequence of the consistency of the surface top layer. It is therefore suggested by a number of authors that reduced maintenance contributes to a more uneven surface and is associated with a higher risk of injury (Kai *et al.,* 1999: Parkin *et al.,* 2004a; Peterson and McIlwraith, 2008; Williams *et al.,* 2001).

Research has shown that maintenance procedures have positive and negative effects on surface characteristics. Peterson and McIlwraith (2008) compared mechanical properties of a dirt race track surface after two types of maintenance procedure. The first maintenance procedure involved using a harrow and grader to produce a partial compaction of the layer underneath the loose surface top. The second procedure involved using a pavement ripper to cut nearly three times the depth into the surface compared to the previous equipment. A rototiller was then used to break up the newly turned surface and it was finally rolled and harrowed. The authors reported that the average peak load measured following the second procedure was significantly ($p<0.05$) reduced in comparison to the first. It is important however to note that the standard deviation was found to greatly increase suggesting that the track was much less consistent after the second procedure, which as previously mentioned is a risk factor in itself. The effect of different maintenance procedures and equipment currently used on existing surface properties is therefore of much interest.

Determining the ideal surface to produce optimal performance whilst paying attention to horse welfare will need further work encompassing many different types of tests and technology. Peterson and McIlwraith (2008) suggest using epidemiological data alongside mechanical track characteristic tests in retrospective studies to provide a whole picture of the horse surface interaction. For non retrospective work however Thomas and Peterson (2008) suggest that studying surface characteristics alongside biomechanical analysis of the living horse would give researchers a greater knowledge of this subject area.

1.5 Biomechanical Analysis

1.5.1 Motion Capture The use of motion capture for analysis of equine gait has been carried out since the late 19^{th} century (Clayton, 1998). In the last ten years there has been a dramatic acceleration in the development of hardware and software available for computer aided systems of motion analysis (Hobbs *et al.,* 2010). The use of such systems allows for a quantitative evaluation of locomotion, removing some of the subjectivity that qualitative analysis can bring (Clayton and Schamhardt, 2001). Use of two dimensional (2D) and three dimensional (3D) videograhic recording systems allow analysis of only the geometry of movement thus providing kinematic data, when used alone therefore they do not take into consideration the forces responsible for such movement (Clayton and Schamhardt, 2001). Videographic systems can however be used in conjunction with equipment capable of providing kinetic related data, such as force plates, accelerometers and strain gauges to provide a more in depth biomechanic analysis (Back, 2001; Clayton, 1998; Hobbs *et al.,* 2010). The large amounts of equipment needed to analyse so many occurrences at once however can prove difficult to fund especially when studying horses as opposed to humans. Testing of the equipment in field is in many cases still in its infancy. The introduction of horses into the equation raises issues regarding both the safe organisation and utilisation of the equipment and the animal simultaneously.

1.5.2 Motion analysis Motion analysis in its simplest form can be done using adhesive markers applied to specific regions of the horse in conjunction with an electronically shuttered video camera based system (Hobbs, 2009). Measurements of 2D joint angles and stride characteristics for example could then be taken manually from the images using specialised software. Recording of data for motion analysis is now however increasingly being carried out using a video based optoelectronic systems where either light emitting or retro-reflective markers are placed on the subject (Morris and Lawson, 2009; Weller *et al.,* 2006). A number (minimum of two) of video cameras are used which emit and detect infrared light allowing tracking of the markers in a predefined volume (Hobbs *et al.,* 2010) to within an accuracy of currently 0.6mm (Pfau *et al.,* 2005). The markers create a local co-ordinate system which relates to the specific bone or body segments to be studied allowing easy identification via the software (Morris and Lawson, 2009). Human error or discrepancies between users, sometimes encountered when manually drawing in measurements such as limb angles, is therefore reduced.

1.5.3 Marker movement The use of skin markers to measure joint movement in both 2D and 3D work relies upon marker placement accurately representing the position and therefore movement of the underlying bone. The problem is that the skin moves over the surface of the bone and this displacement can cause error when interpreting the data (Chateau *et al.,* 2006a; Clayton, 2010; Lanovaz *et al.,* 2002). Corrective algorithms have been developed for various bones and joints to correct these errors (Khumsap *et al.,* 2004), however there are still only a limited number available (Hobbs *et al.,* 2010). It is also important to note that such algorithms are only valid for horses of similar conformation and type, moving in the same gaits as those of the original study (Back, 2001; van Weeren *et al.,* 1990). Lanovaz *et al.* (2004) described algorithms for 3D work for the tibia and third metatarsus, and Sha *et al.,* (2004) described that for the radius. Correction algorithms for the pastern region however have not yet been devised but work using bone pins has helped to determine the movements seen in this area.

1.5.4 Bone pinning The use of bone pins to report true bone movement minus the errors of skin displacement is an accurate but invasive method often meaning that subject numbers are limited when compared to work with non-invasive markers (Chateau *et al.,* 2006a). Clayton *et al.* (2007) reports however that even with the use of bone pins rather than markers, the margin for error regarding placement is large. Distal limb joints such as the proximal interphalangeal (PIP) and distal interphalangeal (DIP) have such small ranges of movement in the transverse and dorsal planes that even small error in bone marker placement can produce inaccurate findings. Bone pinning is, as mentioned, an invasive procedure and the presence of the pin may therefore affect the horse's natural movement by causing some degree of lameness though van Weeren *et al.* (1990) reports pinning had no effect on normal locomotion. Back (2001) states that problems arising from displacement of skin are greatly reduced distal to the carpus, meaning that the use of invasive bone pinning procedures are not vital in distal limb work.

1.5.5 2D and 3D analysis Historically 2D systems have been used to study biomechanics of the horse and the same can be said for the human. Researchers in human sport science have however suggested that studying naturally 3D rotations and translation of joints can give misleading results when interpreted by such single plane analysis methods (Gard *et al.,* 1996). As motion in the equine limb has often been described as pendulum like, with movements of flexion and extension mainly in the sagittal plane, it could be assumed that certain stride characteristics require only simple 2D recording systems (Back, 2001; Clayton 1998; Khumsap *et al.,* 2004). Accurate 2D analysis is however reported (Weller *et al.,* 2006) to rely on zero deviation in the horse to camera angle when using standard electronically shuttered video equipment. A fetlock joint for example would demonstrate more or less extension or flexion than had actually occurred if the limb under investigation was not directly perpendicular to the camera. Work by Ramakrishman and Kadaba (1991) did however report that misalignments of the flexion and extension axis had little effect on the joint angle values of humans measured in 2D where flexion or extension were the dominant movements. The use of 2D measurements where flexion and extension dominate should therefore not be completely overlooked especially when using an optoelectronics based capture system as opposed to an electronic video camera set up. Use of such a system and marker set when studying equine motion would give fewer errors as this type of data acquisition is not affected by the camera position relative to the subject (Unt *et al.,* 2010; Weller *et al.,* 2006).

The development of such specialised motion capture technology has allowed recent studies to look at 3D as well as 2D rotations of the hoof and distal limb joints (Chateau *et al.,* 2006a; Chateau *et al.,* 2010; Khumsap *et al.,* 2004; Weller *et al.,* 2006). The way in which the hoof lands naturally as well as how it lands when treated with remedial farriery have been much researched. It is however less well reported how the normally shod hoof lands on differently maintained surfaces. It has been shown with the use of heel and toe wedges that unnatural landing angles of the hoof can affect the naturally small rotations of the MCPJ (Chateau *et al.,* 2001) and the sagittal plane kinematics seen in the interphalangeal joints (Chateau *et al.,* 2006a). Such effects are suggested to have a negative impact on the health and wellbeing of the horse as a number of the movements caused by uneven foot bearing are observed in the aetiopathogenesis of distal limb injuries (Chateau *et al.,* 2001). It is therefore important to know how different surface substrates or treatments will affect the landing of the hoof and the motion and forces felt through the limb. The use of 3D motion analysis to measure complex movement of the hoof on landing and extension of the MCPJ in relation to arena surface characteristics is therefore an area open to new research.

At present there has been little work done regarding 3D motion of the hoof and limb in relation to changes in mechanical surface properties caused by maintenance procedures. For this study it was important to develop a non-invasive 3D marker set that would be able to repeatedly measure any potential differences in movement of horses on two different preparations of a single synthetic surface. Previous research was important for development of this marker set.

1.6 Aims and Objectives

Developmental Aims

To identify and validate a motion analysis marker set and camera set up suitable for collecting 3D data of the limb and hoof in an outdoor environment.

Developmental Objectives

To design a marker set suitable for collecting measurements of movement of the distal limb and hoof in 3D. To evaluate the marker set in the field using specialist 3D motion analysis infrared cameras and equipment. To trial different camera settings to successfully collect motion data in challenging lighting conditions.

Study Aim 1

To compare movement of the distal limb and hoof following two preparations of a single synthetic arena surface.

Study Aim 2

To evaluate the effect that two commonly used arena maintenance treatments have on mechanical surface properties.

Study Aim 3

To investigate the relationship between movements of the limb and hoof and the mechanical properties of a single synthetic arena surface following two different preparations.

Study Objectives

- To prepare a waxed synthetic surface (Andrews Bowen Pro Wax) in two different ways using standard arena maintenance equipment that is commonly used in the United Kingdom; 1. roller and 2. combined harrow and grader.
- To use retro-reflective markers and infrared optoelectronic cameras to record movement of the hoof, inclination of the limb and extension of the MCPJ.
- To measure hardness and traction of each preparation using mechanical apparatus; 1. A Clegg impact tester and 2. An adapted torque wrench.

- To statistically analyse results for both motion of the horse and mechanical surface data.
- To investigate the relationships between movements of the limb and hoof, mechanical surface properties and surface treatments.

Study hypothesis 1

There will be significantly greater hoof rotation and displacement following harrowing compared to rolling.

Study Hypothesis 2

There will be significantly less MCPJ extension and MCIII inclination following harrowing compared to rolling.

Study Hypothesis 3

Hardness and traction will be significantly lower following harrowing compared to rolling.

Ethical Approval

Risk assessments were completed and ethical approval was obtained from the School of Sports, Tourism, and the Outdoors at the University of Central Lancashire and Myerscough Ethics Committee (Appendix, A, B and C) before commencement of the study.

Chapter Two – Equipment Validation

Development of suitable marker set and validation of optoelectronic cameras for outdoor data collection.

2.0 Introduction

The experimental nature of infield data collection meant that the specialised Qualysis™ camera system used required developmental work regarding set up and orientation of each unit. Hobbs (2009) reported that such camera systems tracking passive markers are usually confined to covered areas due to light sensitivity levels. All data for the current study however was collected under constantly changing outdoor conditions so it was important that suitable settings were established before commencement of the pilot and main study. Developmental work was required to configure the most suitable marker set for capturing limb inclination and joint angle of the MCPJ as well as rotation of the hoof. Passive markers had to be large enough to be identified by the cameras in challenging conditions but small enough to avoid disturbance caused by the adjacent limb during movement.

2.1 Marker Type

The current study used removable skin markers rather than bone pinning for ethical reasons. The design of the main study was comparative in nature meaning that each horse was marked up only once and then performed both test procedures consecutively. Only one horse was used in the validation stage for testing various marker sizes and configurations. The Optoelectronic system used in the study records motion by emitting infrared light to illuminate markers which are placed over chosen anatomical landmarks. The passive markers reflect the light back to the cameras and light signals are then converted into electrical ones and tracked using specialist software (Morris and Lawson, 2009). Spherical and hemispherical passive reflective markers (Plate 2.1, pg21) were therefore tested for visibility on camera, ability to stay attached to the horse during movement and likelihood of being knocked off by the adjacent limb. Spherical markers consisted of a foam ball covered by a special scotch-lite reflective film with a built-in screw and a two-sided neoprene base (Qualysis, 2011). Hemispherical markers were composed of foam half spheres and were also covered in reflective film but had no neoprene base.

The large spherical markers were marginally better identified by the cameras in comparison to the hemispherical ones due to the intensity of the received signal. Smith *et al.* (1997) concluded that the effect of differing marker size on accuracy of values was very small when using such systems and was not a determining factor for producing reliable data for motion analysis. The hemispherical ones were therefore selected for use on the hoof due to the likelihood of the larger spherical markers becoming displaced during break over.

It was decided consequently to measure the difference in distance along the axis of the two marker shapes and adjust the position of the marker centroid on the recorded data accordingly to account for variation between them. A number of markers (5 spherical and 4 hemispherical) were placed onto a flat surface and a 3D image recorded. The difference in distance along the chosen axis of the two types of marker was recorded and found to be consistently uniform. Work could therefore go ahead using both the spherical and hemispherical markers with data for the hemispherical markers adjusted at the processing stage using the specified measurements taken here.

A number of different adhesive tapes for attaching the markers to the limb were trialled at this point. Motion analyses studies using markers directly on skin generally utilize either double sided adhesive tape or in some cases super glue (Clayton and Schamhardt, 2001; Morris and Lawson, 2009). It was decided that a durable double-sided reinforced tape was suitably effective for marker attachment and was therefore selected for further data collection

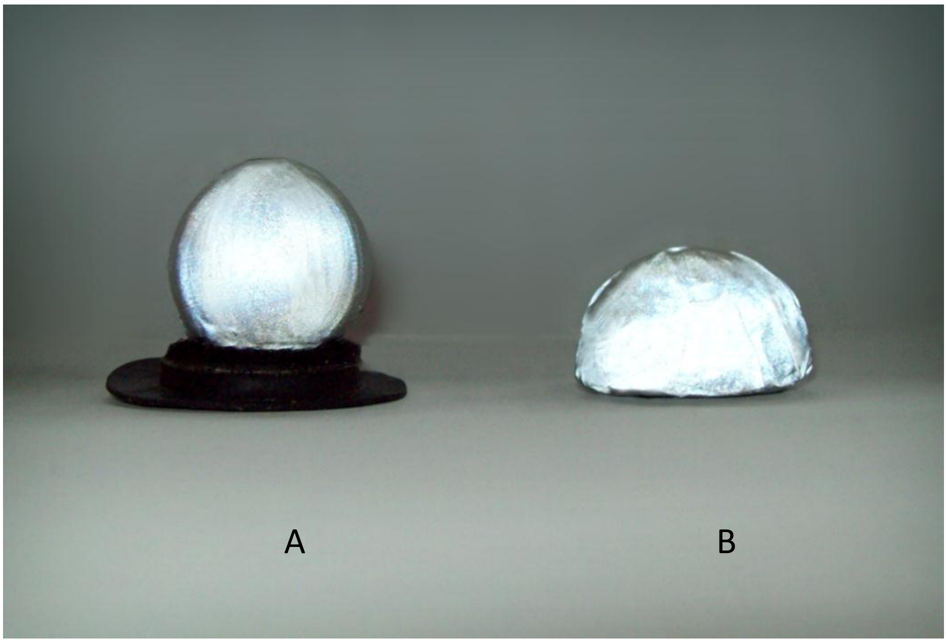

Plate 2.1. Durable, lightweight passive reflective markers. A = Spherical marker (38mm), B = hemispherical (42mm) marker. Markers are foam shapes covered by reflective film (Scotch-lite).

2.2 Marker configuration

There are currently very few skin mounted marker sets used to measure motion of the horses' limbs in 3D. The finalised marker set would therefore need validation against the current standard marker configuration that is used when collecting 2D motion data. At this early stage of pilot work a marker set was devised for 2D and 3D data collection, however the validation work was performed later using the results from the main study.

Identification of the left MCIII, proximal phalanges (PI) and hoof was necessary to produce suitable results for data analysis. The anatomical locations chosen for limb marker placement were adapted from a commonly used 2D set previously described by Clayton and Schamhardt (2001). In place of marking the carpus however the proximal head of the MCIII was chosen, similar to a method recently used by Hobbs *et al.* (2010).

A total of eight spherical and three hemispherical retro-reflective markers (38mm and 42mm in diameter respectively) were placed on the left fore limb of the horse for use in dynamic trials. Two additional spherical markers were also positioned on the lateral and medial distal hoof for a static image to be taken before trials commenced. The static image was used to build a model of the lower left forelimb. Once the static image had been captured the distal hoof markers were removed and the remaining markers for identification of the MCIII, PI and the hoof were used to capture movement data.

Identifiable anatomical landmarks for marker placement (plate 2.2, pg23) were; 1 and 2 - lateral and medial proximal end of the third metacarpus at the head of the second and fourth metacarpal bone; 3- An area offset medially from the middle of the third metacarpal; 4 and 5 -The lateral and medial distal end of the third metacarpus over the collateral ligaments of the MCPJ; 6 - The first phalanx over the common digital extensor tendon; 7 and 8 - The medial and lateral distal end of the first phalanx; 9 and 10 - The medial and lateral proximal end of the hoof wall at coronary band at the location of the DIPJ; 11 -The Proximal end of the dorsal hoof wall at the coronary band; 12 and 13; The medial and lateral distal end of the dorsal hoof wall.

Further to this a marker was placed on the sternum of the horse to allow researchers to actively monitor velocity on each trial for consistency purposes.

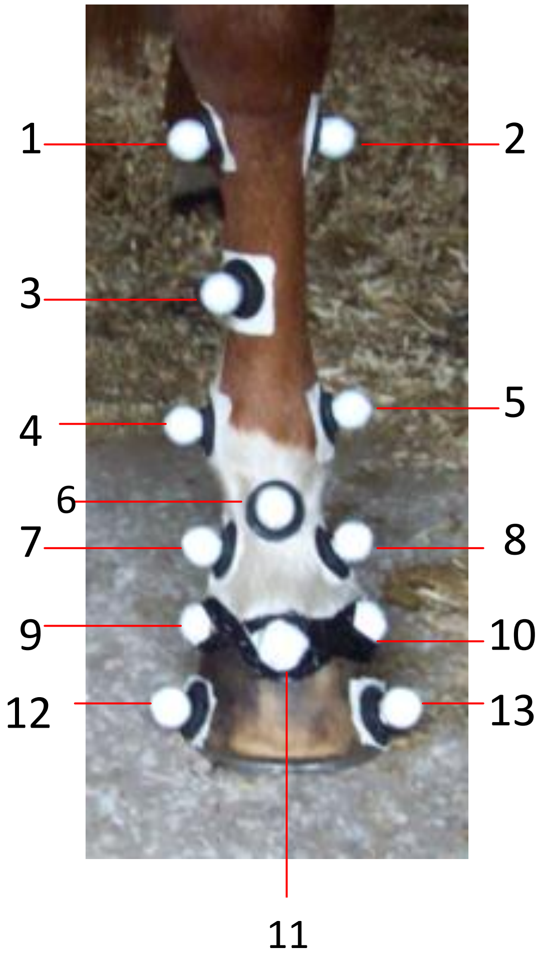

Plate 2.2. Full marker set used for data collection (1-11) including static markers (12+13). 1 and 2 (lateral and medial) - Proximal end of the 3rd metacarpus at the head of the 2nd and 4th metacarpal bone; 3 - Offset medially from the middle of the 3rd metacarpal; 4 and 5 (lateral and medial) - Distal end of the 3rd metacarpus over the collateral ligaments of the MCPJ; 6 - 1st phalanx over the common digital extensor tendon;7 and 8 (medial and lateral) - Distal end of the 1st phalanx; 9 and 10 (medial and lateral) - Proximal end of the hoof wall at coronary band at the location of the DIPJ; 11 - Proximal end of the dorsal hoof wall at coronary band; 12 and 13 (medial and lateral) - Distal end of the dorsal hoof wall.

2.3 Camera set up

Early experimental design testing of the camera set up was vitally important for the current study work to be able to proceed successfully. Optoelectronic camera systems are usually confined to indoor laboratories due to the camera's reduced ability to track markers using the infrared system when in natural outdoor daylight. The current study trialled a new software technique known as active filtering that was developed to be used with Qualysis Track Manager™ and Qualysis Oqus™ infrared cameras (n=3) . Active filtering works by simultaneously laying one frame over another; one that includes natural light captured without using the infrared flashes to capture the background and one that has been captured using the flashes, so this includes natural light and the marker image. The background from one frame is subtracted from the next frame that includes the marker image leaving only the marker image for every two frames of data. This image is then used to construct the 3D view. The system's ability to capture markers in an outdoor environment is therefore reported by the manufacturer (Qualysis™) to be increased when using this hardware. It needed to be decided at this initial testing stage whether the markers could be identified on the moving distal limb of a horse in such challenging conditions with such new and relatively untested hardware.

The cameras were positioned outdoors in a straight line with the fields of view overlapping to enable accurate tracking of a 3D image. The filming area was calibrated using a specialised L frame and marker wand (Plate 2.3). Calibration is necessary to allow the system to accurately record measurements in a predetermined space. The process involves placing the L frame in the chosen data collection area to establish the orientation of the 3D axis in relation to the camera set up. The wand is then moved smoothly and continuously through the space in all directions and orientations whilst being recorded. The horse was led through the calibrated camera setup at walk and trot and data was captured and results monitored on site. The cameras were connected directly to a laptop that showed data collection in real time in a split screen setup to allow researchers to check camera views simultaneously. Motion capture files were therefore analysed during recording for suitable identification of markers whilst using active filtering.

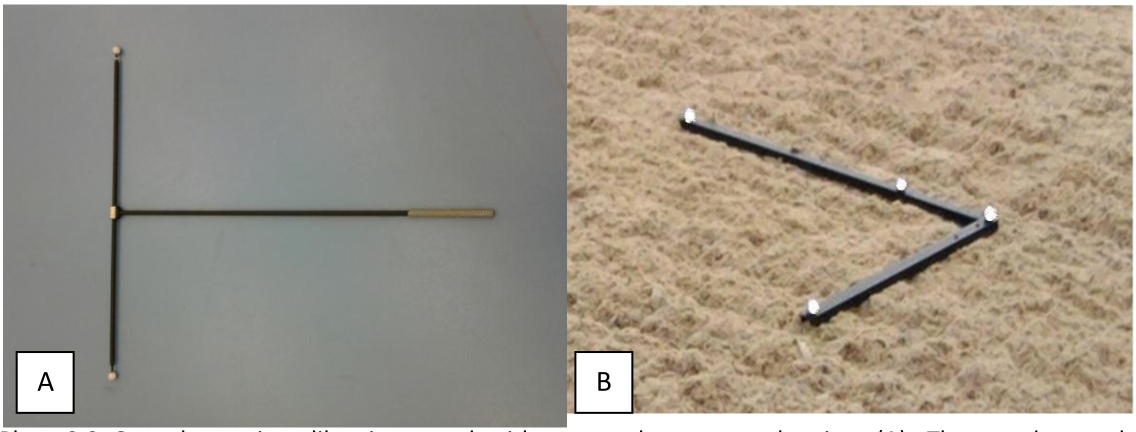

Plate 2.3 Optoelectronic calibration wand with non-coplanar control points (A). The wand must be recorded inside the capture volume for a set time (~60 seconds). Wand motion should be smooth and continuous and cover a 3D volume in all directions and orientations. Optoelectronic calibration L Frame (B) used to establish the orientation of the 3D axis in relation to the camera set up.

The anatomical marker set as well as active filtering proved successful at this early stage of developmental work. It was therefore decided that pilot testing for the main study could go ahead.

Chapter Three - Pilot study

3.0 Introduction

Pilot testing was carried out towards the end of April 2011 and was used to test the equipment and protocol to ensure that the experimental design was reliable and repeatable. All study work was performed outside on a specially laid surface situated at Myerscough College known as the 'Test Track'.

3.1 The Test Track

The testing area was built specifically to be used for study work to eliminate the influence of non research related traffic, degradation and maintenance procedures experienced by surfaces in every day private use. The track was laid in December 2010 and was not used prior to the current study which commenced with pilot testing in April 2011. The track was composed of a number of different layers (figure 3.1) starting with the sub-base of compacted earth, next an impermeable plastic membrane was laid on top of which went a geotextile layer. The track then had a layer made up of Permavoid™ units that are designed to drain the surface and then store the water for further use. On top of the units was a second geotextile layer. The final layer was a synthetic substrate, which consisted of (by weight) 83% silica sand, 15% fibre, felt and rubber crumb and 2 % wax and was laid to 120mm in depth.

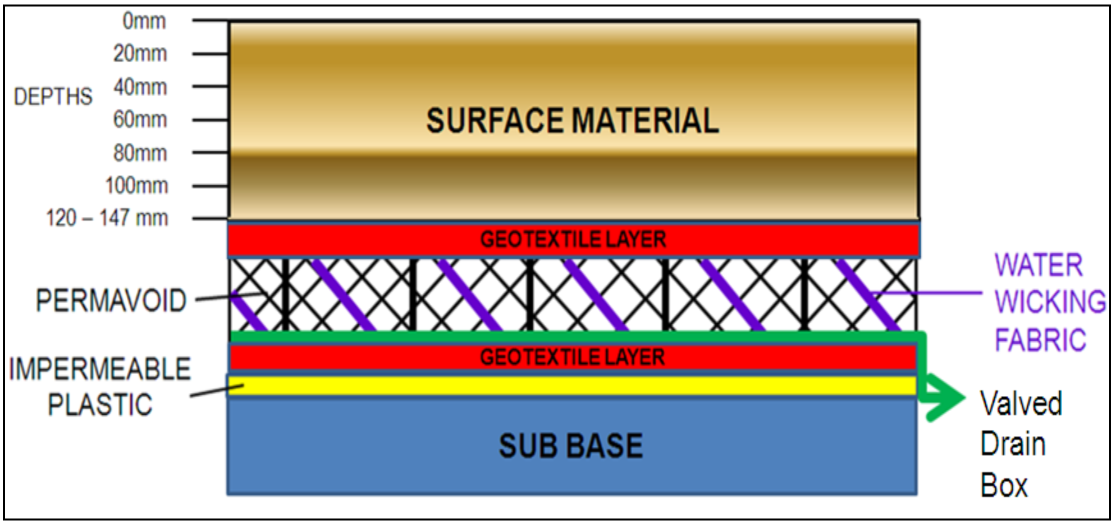

Figure 3.1. Component layers of the test track at Myerscough College. Picture courtesy of Jessica Hawkins, and UCLAN.

3.2 Habituation to the equipment and test track

One horse (14.3hh, 11 years, 553kg, Gelding) was used for the pilot study and underwent a habituation period prior to testing to prevent undue stress and decrease possible risk of injury or abnormal gait. Habituation to the marker set occurred on two different days with behaviour monitored closely at all times to allow the researchers to measure the horse's response to each stage of the process. Initially the horse was safely restrained using a bridle whilst markers were applied to the specific anatomical locations listed in section 2.2 (pg23). The horse was kept in the stable for a fifteen minute period with the markers on and behaviour was closely monitored. The horse showed no signs of stress or discomfort to the presence of the markers and therefore progressed to the next stage. The second stage commenced with reapplication of the marker set on the second day. The horse was then led out of the stable into an arena and finally onto the test track. Behaviour was monitored at all times to identify any adverse reactions to the procedure. Researchers concluded that the horse was not adversely affected by the presence of the markers and that pilot testing could go ahead.

3.3 Camera setup

The camera setup for the study is shown in figure 3.2 (pg27). Eight infrared cameras (Qualysis Oqus^{TM}) were used, which due to the application of active filtering recorded at 245Hz using Qualysis Track Manager ^{TM} kinematic software. Four cameras were positioned on the left hand side of the track with the remaining four positioned opposite. The cameras were connected to each other for simultaneous use and were then connected to a laptop positioned in a covered area to one side of the track. Camera placement and heights were altered until a suitable set up was reached that allowed researchers to record several strides per trial. Cameras were positioned so that each camera's field of view overlapped at least one other adjoining camera (plate 3.1, pg27), as is standard practice for biomechanic analysis under field conditions (Miro *et al.,* 2009). Wires were kept on the outside of the test surface area with the exception of one cable that crossed the track buried under the substrate in specifically designed rubber housing.

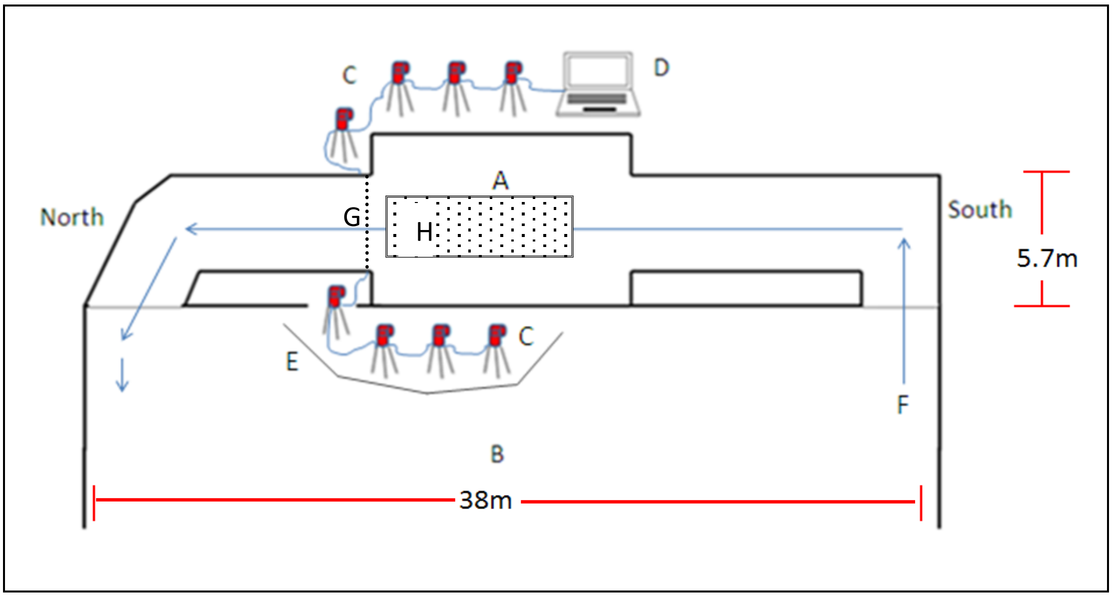

Figure 3.2. The film set up. A = test track, B = adjacent arena, used for cool down of horses during testing, C=motion capture cameras, D= laptop, E= safety barriers, F= direction of movement through the camera run, G= area where camera cable crossed the track buried in a specially designed rubber housing, H= calibrated filming zone.

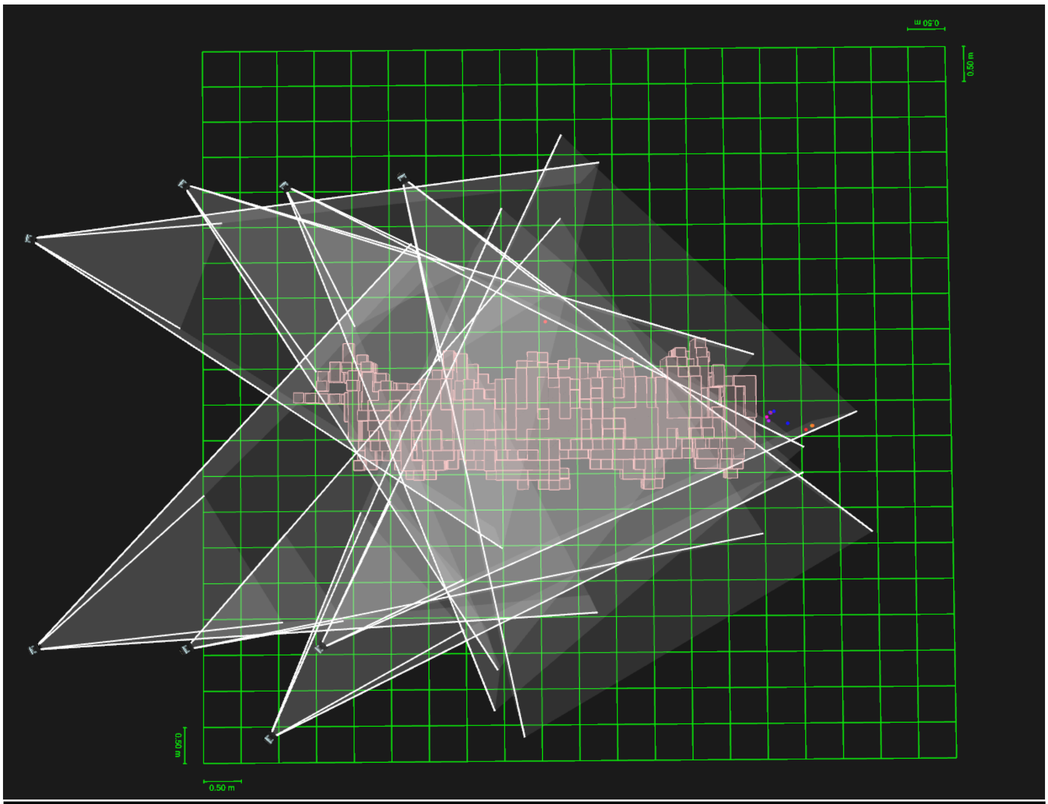

Plate 3.1. Overhead image of the calibrated filming zone used for pilot testing. Overlapping camera fields of view are presented in white. The red cubed volume in the middle represents the calibrated volume that data is collected within. The green grid shows the floor surface area.

3.4 Anatomical Markers

Markers were applied to the left forelimb and sternum as detailed in section 2.2 (pg 22).

3.5 Arena Treatment

Two standard maintenance procedures that produced different finishes on the surface were chosen to be used in the study. Treatments were chosen based on information collected regarding suggested maintenance procedures for synthetic surfaces from a number (n=9) of telephone interviews with providers of equestrian surfaces (Appendix E). Treatment one involved using a piece of equipment that comprised of a harrow and grader, known as an Arena Mate™ (plate 3.2A). The surface when treated and visually assessed appears even but with a loose top layer. Treatment two was a standard roller (plate3.2B) which appears to flatten and compact the surface when visually assessed.

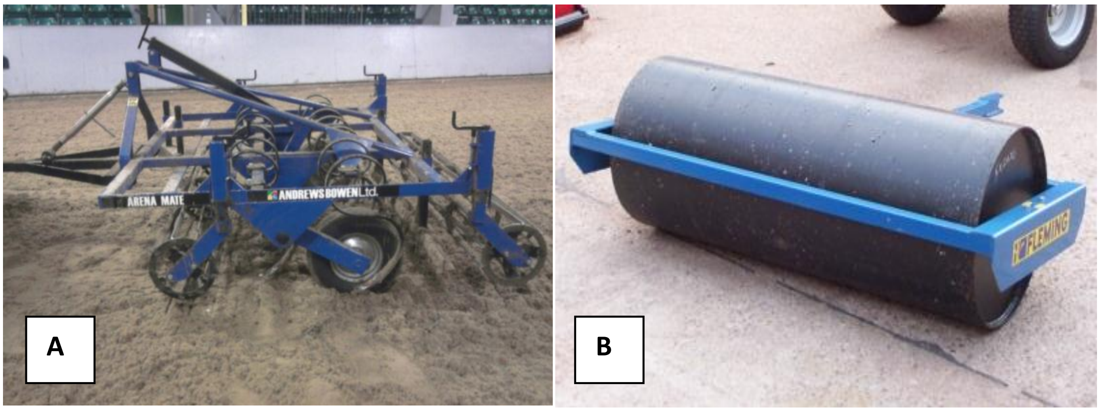

Plate 3.2. A combined harrow and grader (A) comprises of eight tines and two revolving graders. Surface roller (B) used for turf and arena surfaces. Weight of roller = 300 Kg. Width = 2m (landscapemachinery.co.uk).

Prior to commencement of the pilot study the two treatments were tested on the surface using various levels of application and the visual effect on the substrate assessed. Accessing the track with a tractor and equipment was trialled a number of times. Researchers needed to be able to accurately manoeuvre a heavy vehicle onto and across the area whilst avoiding compacting the newly treated surface. The information gained here was used alongside the manufacturer's recommendation to decide on the final treatment procedure. Finalised test treatments involved pulling the equipment north to south down the track in two parallel strips then back up the track from south to north over the centre of the two previous strips (figure3.3, pg 29).

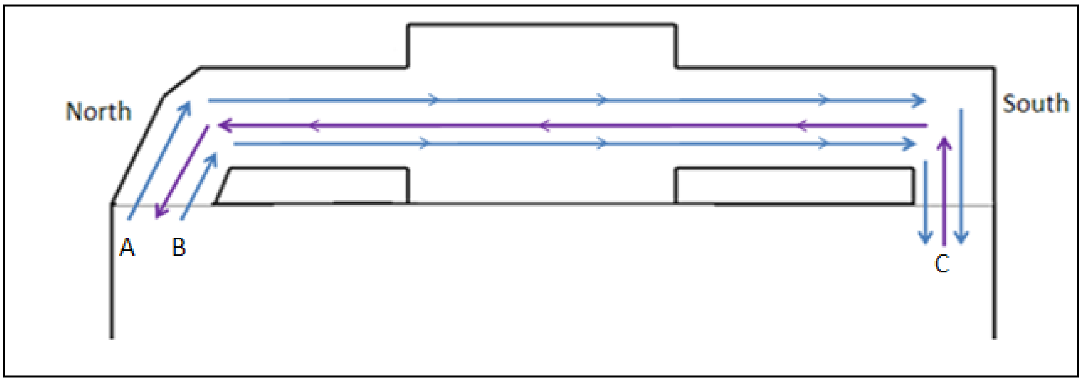

Figure 3.3 Direction of application of arena treatment. A= 1St pass North to South; B=2nd pass, adjacent to A, North to South; C= 3rd pass South to North overlapping the inside area of both A and B.

3.6 Filming procedure

A static image of the full marker set was taken with the horse stood with limbs squarely positioned; additional markers (12 and 13, section 2.2, pg22) were then removed and trials commenced. The surface was treated using the first maintenance procedure and the horse then ridden in walk, trot and canter through the test track. Treatment two was applied to the surface and the procedure repeated. The horse was led in hand for ten minutes to cool down in the adjacent arena then safely put away with all markers removed. It was decided that the necessity in the study to carry out walk work before moving into faster gaits during filming meant that the horses would not need a set warm up prior to commencing filming.

3.7 Sample size

Previous studies of a similar biomechanical nature have measured limb and hoof movement using sample sizes of between four and six horses. Chateau *et al.* (2005) reported 3D joint angles and range of motions (ROM) for hoof rotations and distal limb segments using four horses. It should be noted though, that unlike the current study, an invasive bone pinning procedure was used. A more recent study however by Chateau *et al.* (2010) investigated hoof landing parameters on different surface substrates via non invasive techniques also using four horses. Results from the work were analysed using a general linear model test. Further to this work by Hobbs *et al.* (2011) reported inclination of the limb using six horses in a non-invasive, cross over design similar to that used in the current study. As this study was testing a difference in preparation of the same surface it was expected that differences in kinematics would be more subtle, so the sample size was increased to ten horses to provide sufficient power to carry out a statistical analysis of the results.

Chapter Four - Investigation of treatment effects

4.0 Introduction

The main investigation took place over eight different dates during May and June 2011; day 1 = 05/05, day 2 = 06/05, day 3 = 13/05, day 4 = 19/05, day 5 = 27/05, day 6 = 02/06, day 7 = 03/07. All work was carried out on the test track used in the pilot work (section 3.1, pg25).

Ten horses (5 geldings, 5 mares; mixed breed; mean ± SD – height 15.2 ± 1.3hh, age 11.1 ± 2 years, weight 540.8 ± 98.6Kg) that were deemed sound and fit were used for the main study. Horses were shod with standard iron shoes on all hooves, at various dates prior to testing. All horses underwent similar regular workloads throughout the course of the research and were habituated to the equipment prior to testing in the same manner as described in section 3.2 (pg26). Allocation of filming dates and surface treatment order was randomised for each horse.

One rider was used throughout the study to decrease inconsistencies arising from riding styles and understanding of testing procedures. The same rider was chosen that completed the pilot study and was very experienced in equestrian sports having competed at national and international level. The rider was briefed regarding the study aims and procedures and consented to the work before commencement of data collection (Appendix D).

4.1 Camera setup

The camera setup for the main study is shown in figure 3.2 (pg27). Heights and distances between cameras were decided so that an area of ~three metres wide and ~seven meters long was visible from the camera reconstruction.

4.2 Anatomical Markers

The marker set previously devised in the pilot study was used for the main data collection work (plate2.2, pg23). Markers were applied in the stable whilst the horse was held by a competent handler; this procedure was performed by the same person for every horse for consistency purposes. Double sided adhesive tape cut into squares approximately four cm by four cm was used to secure the markers to the limb. Surgical tape was then used to form a figure of eight pattern over the markers of the hoof to ensure minimal displacement from original positions. Horses had a full marker set initially applied which included those used for the static image.

4.3 Arena Treatment

Surface treatment order was randomised on each day for every horse. One researcher applied treatment one and a second applied treatment two. Researchers did not change treatment type for consistency purposes as past research (Blundell *et al.,* 2010; Kai *et al.,* 1999) has attributed varying results of mechanical properties of surfaces to the difference between users of maintenance equipment. The two researchers together judged the final outcome of the treatments and if treatments were deemed inconsistent in relation to findings in section 3.5 (pg28), then further treatment was applied.

4.4 Filming procedure

Camera setup and treatment procedure were carried out as detailed previously in section 4.2 and 4.3 respectively. Horses were prepared in a stable and then brought out to the track one at a time with a maximum of two horses tested within any one day. Horses were led in hand through the camera set up on the track to familiarise each one with the filming equipment. The horse was then positioned in hand within the calibrated area and a static image taken. The extra markers needed for the static only were removed (12 and 13, plate 2.2, pg23). The rider mounted and the horse walked onto the test track at one end, through the camera setup and then off the track at the opposite end (figure 3.2, pg27). The process was then repeated twice more so that in total there were three original attempts in walk. Throughout data collection researchers monitored the horse's speed through the camera run. The velocity of the sternum marker was analysed using the Qualysis Track Manager™ program which could calculate and display the data in graph form within seconds of it having been recorded. If the horse was travelling at too high or low a velocity compared to its other attempts the rider was asked to complete an extra recorded trial. Once three successful velocity matched runs in walk had been made, the rider repeated the process in trot and canter (Plate 4.1, pg32). Successful velocity matched trials were deemed to be within 0.2m/s of each other. The horse was then taken into the adjacent arena whilst treatment two was applied to the surface and the data collection process repeated. Horses were led in hand for a ten minute cool down period after testing and safely returned to the stable, all equipment was then removed.

Plate 4.1 A horse completing a successful trial in canter.

4.5 Mechanical surface properties

4.5.1 Hardness measurements

Hardness measurements (G) were taken using a Clegg impact testing device (plate 4.2) after completion of data collection for each horse on both surface treatments. In total 15 sections that were deemed to undergo the most traffic during data collection were tested. Rectangular sections measured approximately 1.3 x 1.8 metres and are shown in figure 4.1 (pg33), the sections numbered 51-65 were those tested. Five drop readings were taken in different places within each rectangle to give a mean hardness value for that specific area. Each drop followed the procedure laid out in the Clegg standard operating procedure which can be found in the appendices (Appendix F).

Plate 4.2 Clegg Impact Testing device. A= digital display meter. B= 2.25Kg drop weight fitted with accelerometer. C= Hollow guide tube.

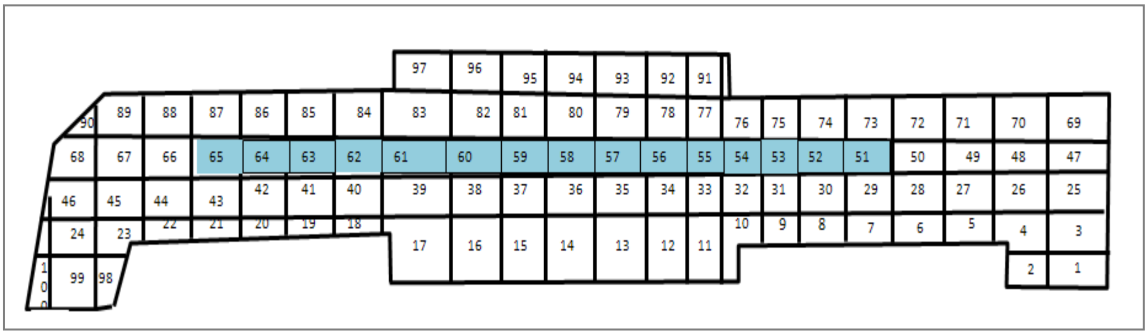

Figure 4.1. Track surface testing grid. Areas 51-65 (shaded in blue) were tested for hardness using a Clegg impact tester after each treatment data collection. The large amount of squares that were not used in the current study were numbered for use in unrelated test work.

4.5.2 Torque measurements

Measurements of the surface were taken to give an indication of shear force. A torque wrench with an adapted base plate specially made to mimic the equine hoof was used (plate4.3). Test track grid squares 51-65 (figure 4.1) were measured with a repeat of five drops in each square from which a mean value was taken. Care was taken to measure torque on areas that had not been deformed by the Clegg Impact tester or the horse enabling the researchers to get a true shear strength reading for each treatment. Each drop followed the procedure laid out in the torque wrench standard operating procedure which can be found in the appendices (Appendix F).

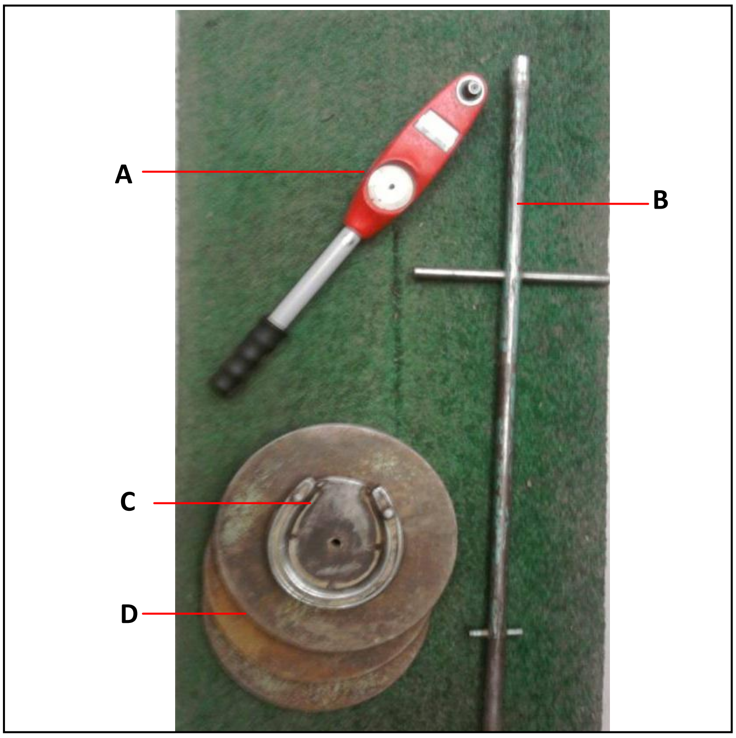

Plate 4.3. Torque wrench split into component parts. A = Torque wrench. B = Connecting section with handles to lift and operate equipment. C = Specially adapted base plate. D =. 10Kg weights

4.5.3 Moisture Content

Surface samples were collected from the test track on testing days and then tested under laboratory conditions in a method similar to Peterson and McIlwraith, (2008) in order to determine moisture content. Samples were collected from the North and South of the track and divided into triplicate, resulting in six samples for each test date (n=49). Samples were all weighed at 100grams =/- 0.1g, labelled and then placed in a temperature controlled oven at 40 degrees Celsius for a twenty four hour period. Samples were then removed, cooled for thirty minutes and re-weighed to calculate moisture content.

4.6 Data processing

Data processing occurred in a number of stages and involved using Qualysis Track Manager™ and Visual3D™ computer programs to take the data from the captured motion information through to actual metric values that could be statistically analysed.

4.6.1 Stage one- Limb modelling Using the Qualysis Track Manager™ software a model was constructed to represent the limb segments of the horse. The model was then applied to each subjects separate static file to pertain to the exact measurements and angles of each horse tested. All recorded trials were then cropped to one stance phase per horse, starting just before impact and finishing just after toe off (plate 4.4). Exact points in the stride phase were later identified in Visual3D™.

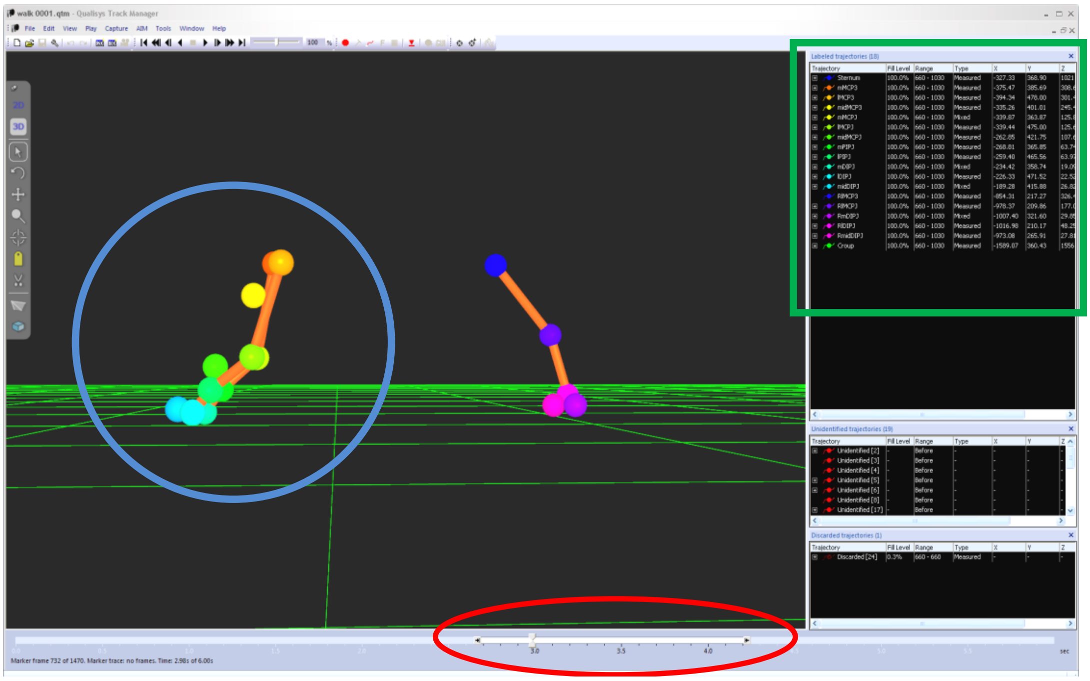

Plate 4.4. Analysis of walk using Qualysis Track Manager ™. The limb circled in blue was analysed in the current study. The time line along the bottom has been cropped to one stance phase (circled in red). The Box highlighted in green shows the co-ordinates in X, Y and Z of the different markers at any point on the data clip.

4.6.2 Stage two – Individual static measurements In Visual3D™ each horse had a separate file containing the relevant dynamic trial data for all gaits on both treatments. At this point the program needed to be able to identify the specific measurements of the limb segments for individual horses' and link them with the relevant kinematic data. The system does this by applying the particular static image (plate 4.5) that was taken before testing and applying it to the appropriate motion files. The static image represents the measurements of that horse whilst stood and takes into account the individual horses' weight and conformation. The axial distances of the hemispherical markers used on the hoof to collect motion data were edited at this point to match those of the spherical markers (plate 4.5), using measurements detailed in section 2.1 (pg20). Transformation then occurred to scale the data via integration of calibrated information to the digital co-ordinates captured.

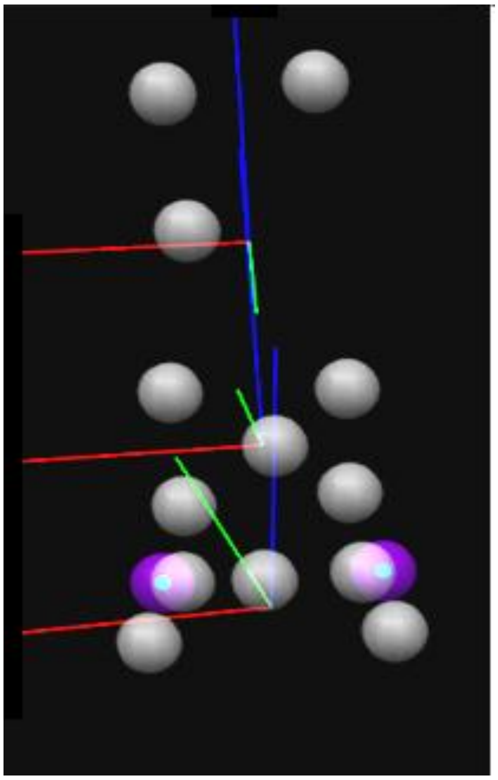

Plate 4.5 Model building of the distal segment of the left fore limb in Visual 3D, complete with segment axis. Purple markers indicate hemispherical markers used and individually adjusted for data analysis.

4.6.3 Stage three – Identification of events A low pass digital Butterworth filter with a cut off frequency of 15Hz was then used to smooth the data. Specific events were then identified to facilitate comparison of values between different horses by standardising certain parameters, in this case phase of stride. Impact, mid-stance and toe off were identified using graphed data alongside motion images as shown in plate 4.6. Impact was identified as being between the vertical velocity minimum and vertical acceleration maximum of the hoof in Z, in a method similar to that previously reported by Hobbs *et al.* (2010). Mid-stance was marked as the point that MCIII became vertical. Toe off was established as being between the subsequent vertical velocity minimum and corresponding acceleration maximum. The motion image of the limb segments (plate 4.6) was used to support identification of events accordingly. Phase of stride was identified in using this method for all trials, in all gaits for each horse.

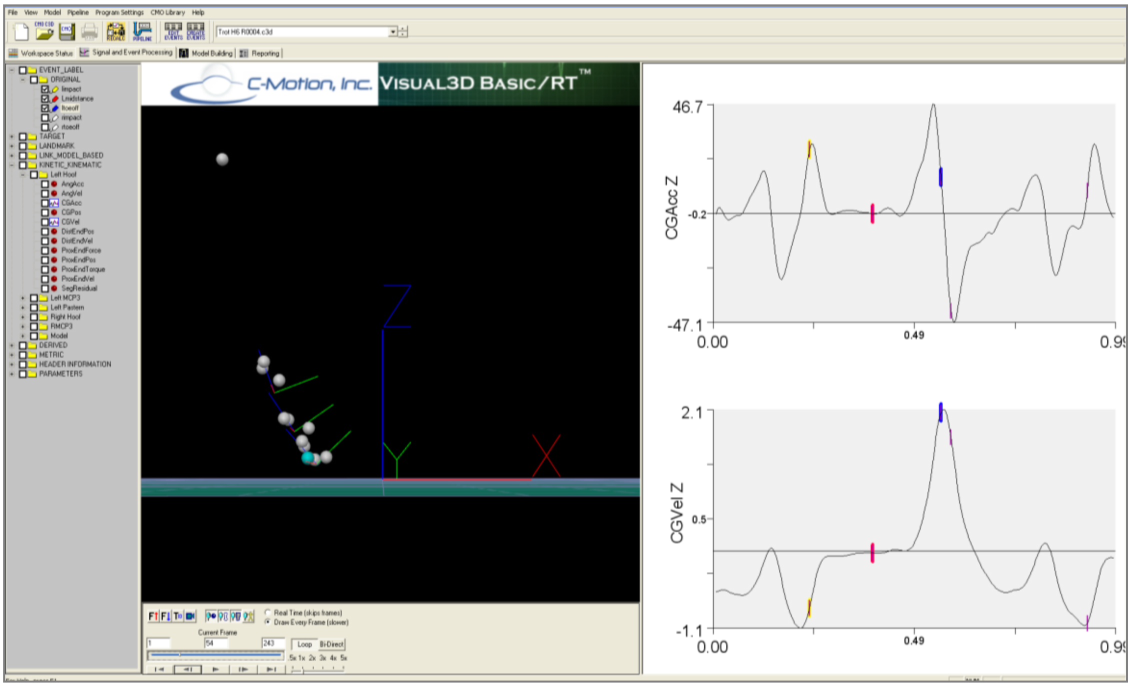

Plate 4.6. Stance phase event identification in Visual3D™ using velocity and accelerations from the distal hoof marker of the left fore limb. The graphs present impact as being between the vertical velocity minimum and vertical acceleration maximum of the hoof in Z (highlighted in yellow). Mid-stance was marked at the point when the MCIII was vertical (highlighted in red). Toe off was established as being between the subsequent vertical velocity minimum and corresponding acceleration maximum (Highlighted in blue). The motion image of the limb segments was used to support identification of events accordingly.

4.6.4 Stage four – Extracting values Trials were grouped together for maintenance procedure and gait for each horse. Absolute values for a given movement were defined in relation to the calibrated lab co-ordinate system (figure 4.2). The segment coordinate system was then used to define MCPJ rotations.

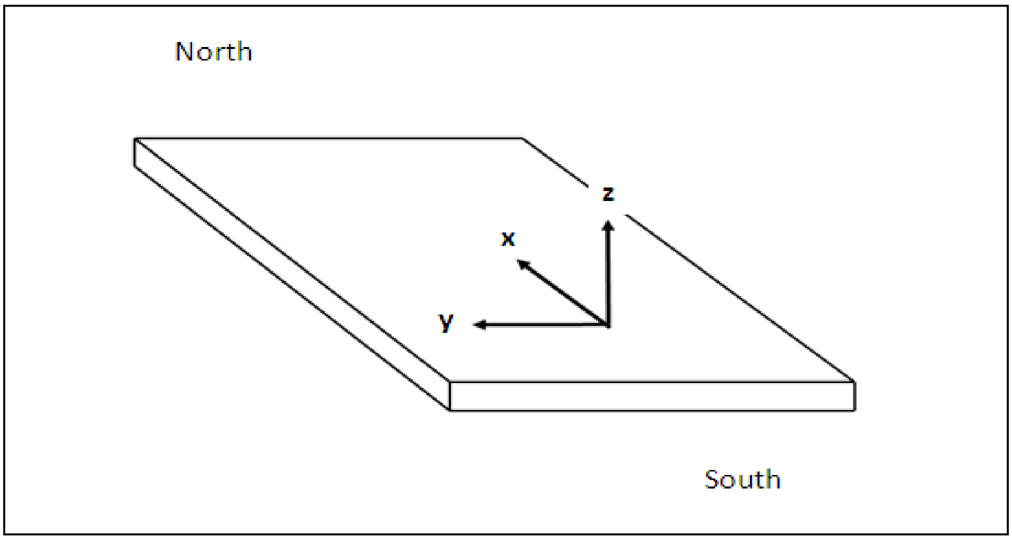

Figure 4.2. Representation of the global coordinate system used to define motion in a given plane in position on the test track used in the current study. Direction of movement for horse motion data was South to North.

Hoof rotation and displacement were calculated from the markers positioned medially, centrally and laterally on the proximal hoof. Figure 4.3 (pg 38) demonstrates use of the global coordinate system in measuring motion. Hoof rotation was calculated as a ROM in degrees from impact to mid-stance and mid-stance to toe off as roll (rotation around X) (medial/lateral = +/- values), pitch (rotation around Y) (forwards/backwards = +/- values) and yaw (rotation around Z) (lateral/medial=+/- values). Hoof displacement was also measured as linear displacement in centimetres and movement was defined as cranio-caudal (X) (cranial/caudal = +/- values), mediolateral (Y) (medial/lateral = +/- values) and vertical (Z) (up/down = +/- values).

Values for 2D and 3D MCPJ extension were calculated as the angle between lateral markers on the proximal 3rd metacarpus, MCPJ and distal PI at mid-stance, impact and toe off (<180° flexion/>180° extension). MCPJ values were defined as flexion and extension (figure 4.4, pg 38). MCIII inclination was measured at impact and toe off as an acute angle from the vertical static limb position (value =0) with roll (medial/lateral = +/- values), pitch (forwards/backwards +/- values) and yaw (lateral/medial = +/- values).

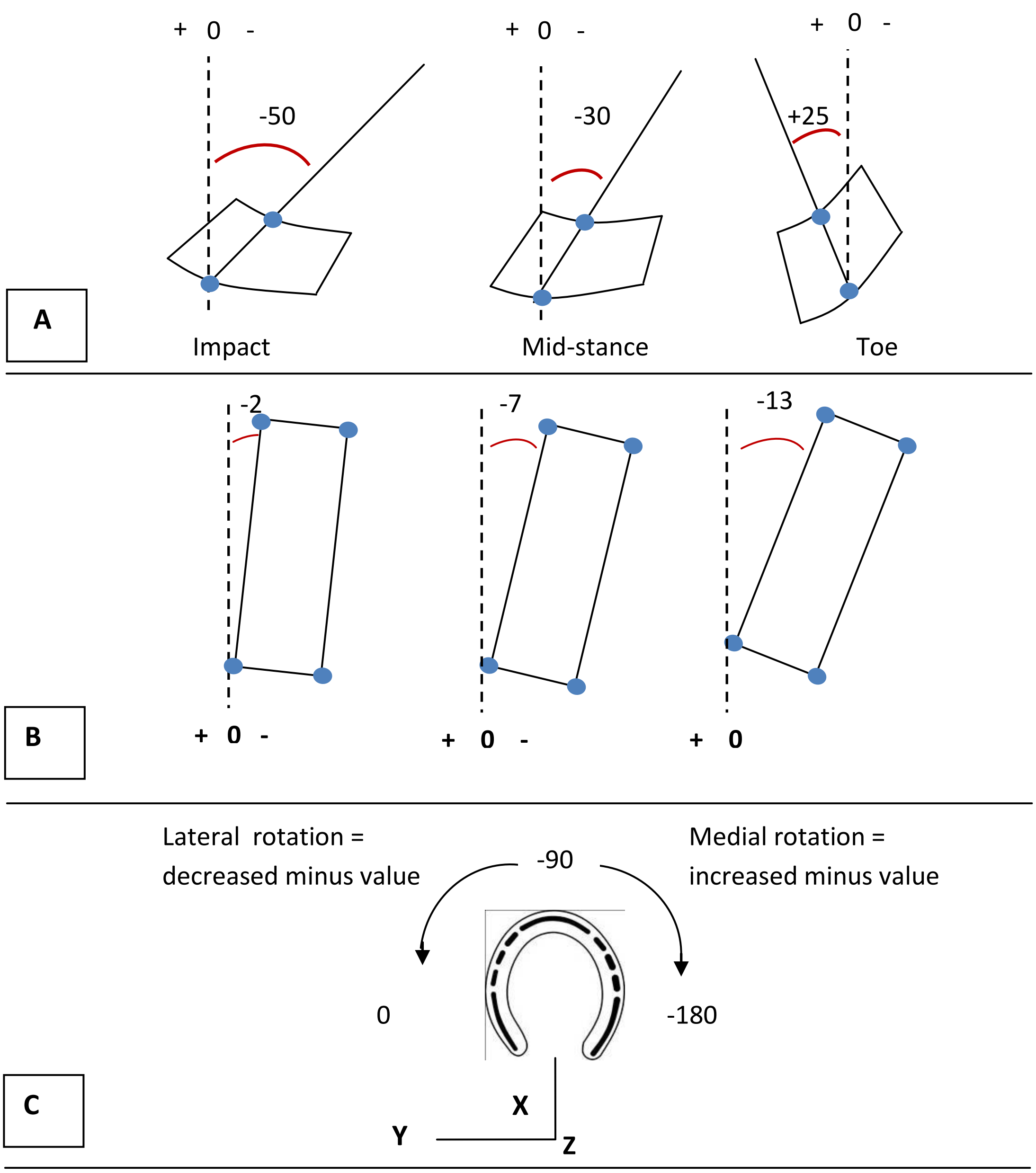

Figure 4.3. Sign conventions for rotation of the hoof and MCIII using the global coordinate system. A) Pitch (forwards/backwards = +/- values), B) Roll (medial/lateral = -/+ values). C) Yaw (lateral/medial= -/+ values).

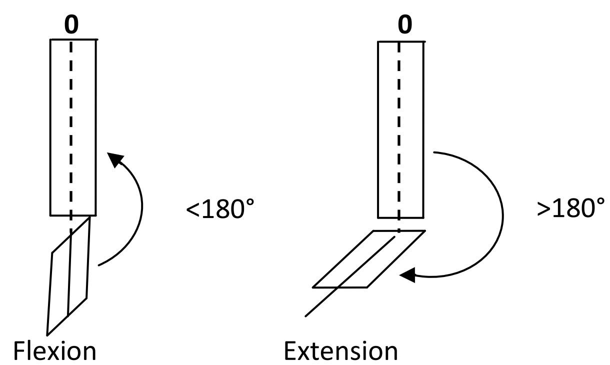

Figure 4.4 MCPJ flexion and extension (<180°/>180° values) calculated as the angle between lateral markers on the proximal 3rd metacarpus, MCPJ and distal PI at mid-stance, impact and toe off.

Graphs (figures 4.5 and 4.6) as well as numerical values for all kinematic data were then exported from Visual 3D as text files and moved into Minitab[16] for statistical analysis.

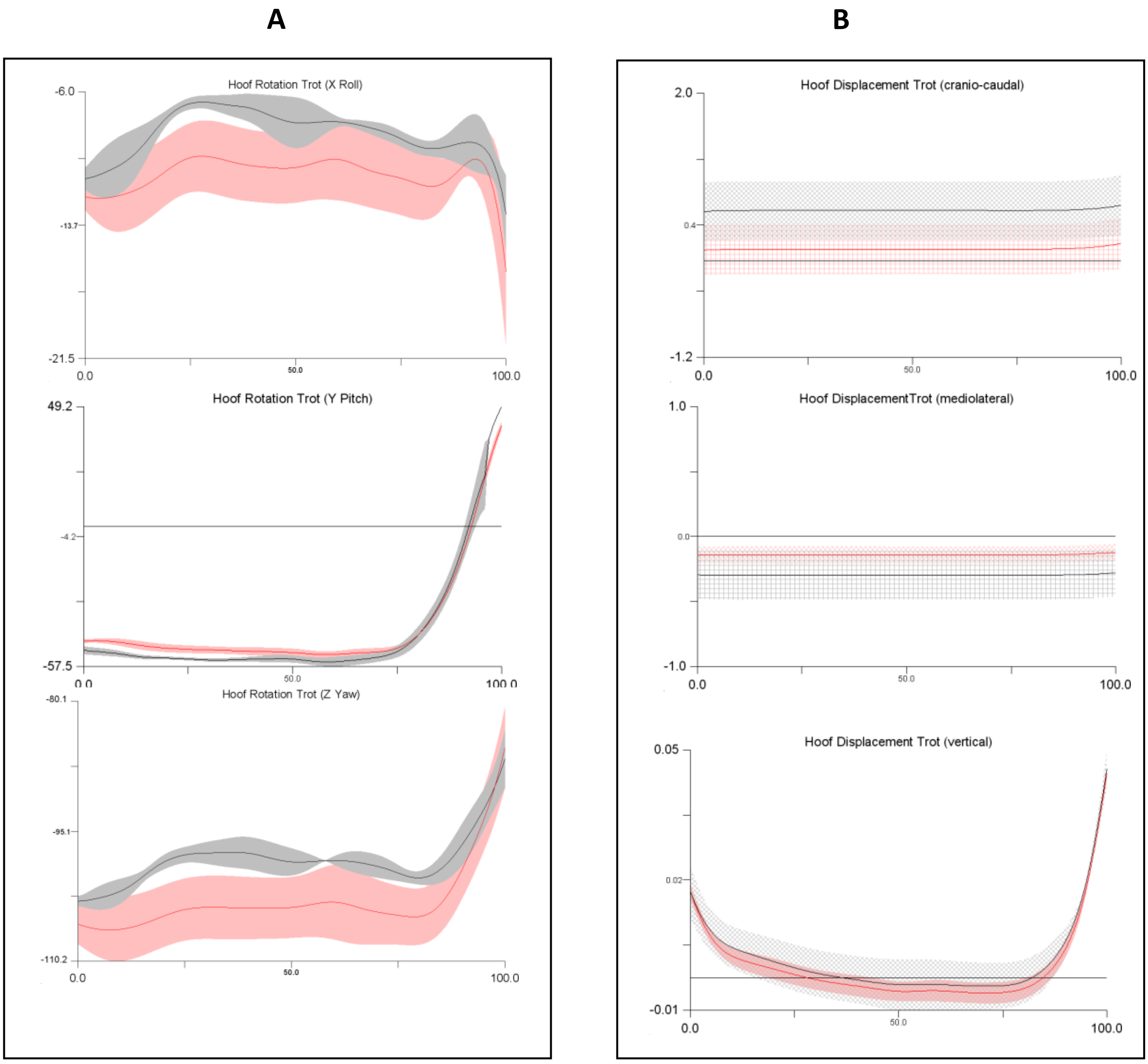

Figure 4.5. Graphs taken from visual 3D of one stride for one horse in trot showing hoof rotation (A) for roll (top), pitch (middle) and yaw (bottom) and hoof displacement (B) for cranio-caudal (top), Mediolateral (middle) and vertical (bottom). The coloured lines represent the mean for all three trials for both treatments (Harrow– Black, Rolled – Red) with the standard deviation appearing as the larger lighter coloured blocks. For all graphs the X axis represents percentage of stance duration.

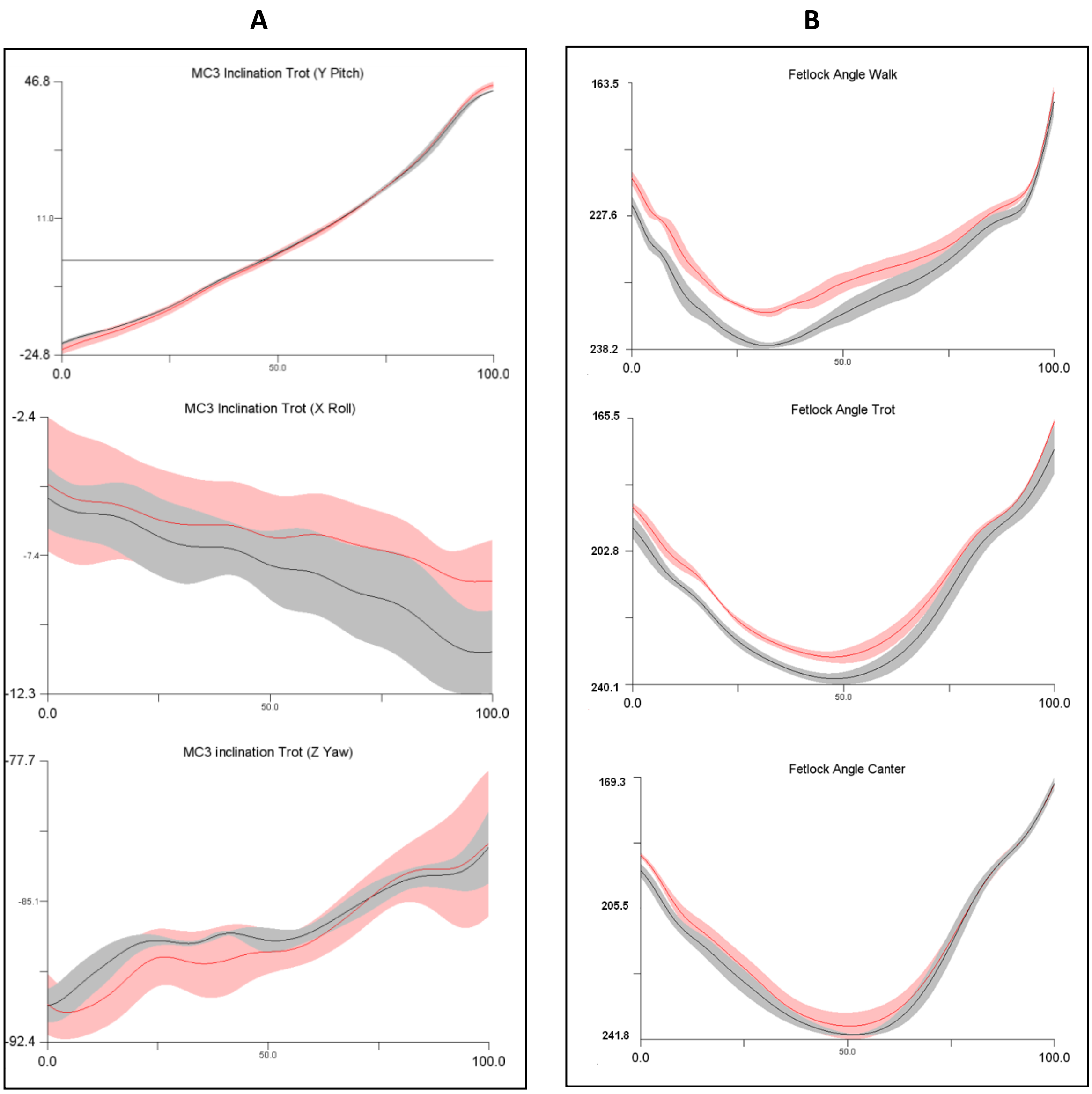

Figure 4.6. Mean MCIII Inclination (A) for one horse in trot for pitch (top), roll (middle) and yaw (bottom). Mean MCPJ extension (B) in X for one horse in walk (top), trot (middle) and canter (bottom) for all trials (with standard deviation) on both treatments; harrowed (black) and rolled (red). Percentage of stance duration is displayed on the x axis for both graphs. MCPJ extension is shown in increasing in extension towards mid-stance then decreasing toward toe off.

4.7 Statistical analysis

All statistical analysis was performed using Minitab[16]. Data was assessed for normality using a Kolomogrov-Smirnov test and judged to be normal. A Pearsons Correlation was performed to validate the use of an adapted 2D marker set for 3D collection of 3D data. A General Linear Model (GLM) was used to test for a significant difference in kinematic values between surface treatments for all hoof and limb movement data. Hardness and shear forces measurements were analysed using a paired t-test to look for significant differences between treatments. Significance was defined at the 0.05 level.

Chapter Five - Results

5.0 Introduction

Horse number three was removed from the study due to inconsistencies caused by the marker set and its ability to stay attached on the day of filming. In total data from nine horses were analysed and reported.

Results for the study are presented in four parts. The first section explains the procedure and results used for validation of the 3D marker set by comparison of 2D and 3D MCPJ extension values. The second section presents the full results for hoof rotation, hoof displacement, MCPJ extension and MCIII inclination on both treatments. The third section details the mechanical surface properties on separate testing days and as overall mean values for harrowed and rolled treatments. The final results correlate the mechanical surface property findings with those from the kinematic analysis that yielded statistically significant values.

5.1 Validation of the 3D marker set

Measurements for MCPJ extension in the sagittal plane (X) were taken from the 3D data and compared to those produced from the same trials using the current standard 2D analysis method. The mean angles for all trials at all phase of the stride were compared between treatments using a paired t test. A significant difference (p=0.001) was found between the two means (table 5.1) showing that the values produced by the two systems were not the same. Accurate measurement of 2D angles of movement in the sagittal plane relies upon the horse being perpendicular to the camera set up throughout data collection. During testing it was not ensured that horses followed a direct track through the camera setup. The angles reported by the 3D capture may differ therefore from those of the 2D, due to its ability to more accurately capture measurements occurring at varying distances to the camera setup. As a result of this the data from the two methods was analysed further to decide whether the 3D measurements increased in a similar manner to that of the 2D throughout the various phases of the stride (figure 5.1, pg44). The 2D and 3D data correlated (p<0.001) with an r value of 0.949 meaning that the two data sets were very closely related and that they increased in a significant linear way. The results from the correlation conclude that the marker set used in the study for 3D movement produced the same magnitude of change in values as the more commonly used 2D set up.

Table 5.1. Mean (n=162) values for 3D and 2D MCPJ extension for all phases of the gait. P values of less than 0.05 denote significance.

Mean 3D MCPJ angle (degrees)	Mean 2D MCPJ angle (degrees)	P Value	Significant
200.5	**202.8**	**0.001**	**Yes**

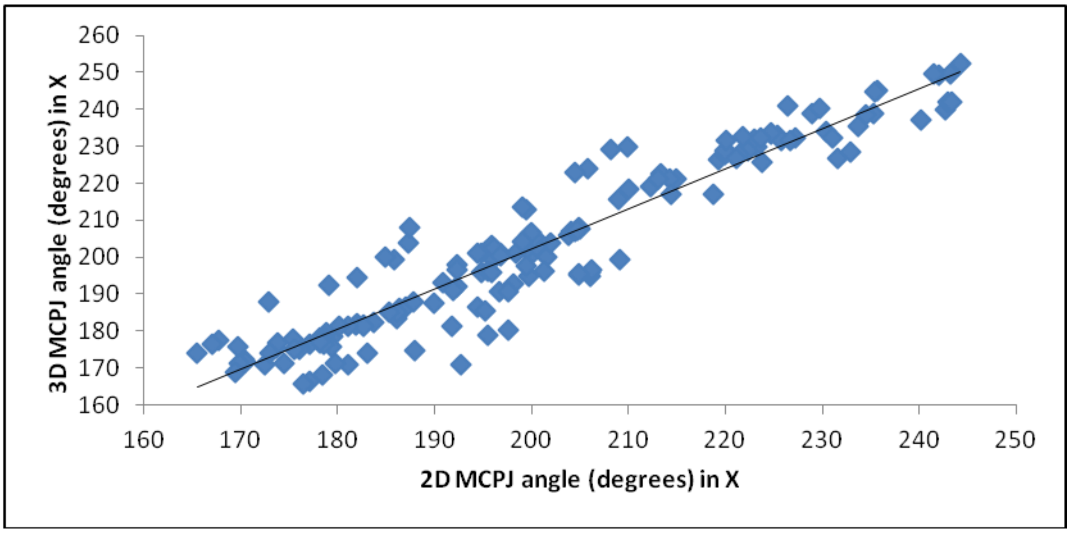

Figure 5.1 Scatter plot comparison of 2D and 3D MCPJ extension data for impact, mid-stance and toe off. Values were found to increase in a significant linear relationship (r=0.949)

5.2 Distal limb and hoof movement between two different surface preparations

Kinematic data for the distal limb and hoof was collected in walk, trot and canter on a single synthetic surface treated with two different maintenance procedures (harrowing and rolling). Trials were velocity matched during filming using a sternum marker to monitor the speed at which each horse travelled through the testing set up. Data was selected for velocities that were within 0.2 m/s for three measurements for each horse for each gait on one treatment. Individual horse velocities were then matched for three further measurements on the second treatment. Data collections deemed to be too high or low a velocity for a horse in comparison to previous successful attempts were discarded (8%) and extra trials collected. Table 5.2 (pg 46) shows the velocities of each horse for the successful trials that were then analysed for kinematic data in the current study. A t-test was performed *post hoc* to ensure data was successfully matched. No significant difference ($p>0.05$) was found between velocities on either a harrowed or rolled surface in any gait for each horse.

Table 5.2. Successful velocity (m/s) matched trials for each horse in walk, trot and canter for each trial and mean average on both treatments.

	Harrowed	Rolled	Harrowed	Rolled	Harrowed	Rolled
Horse	**Walk (m/s)**	**Walk (m/s)**	**Trot (m/s)**	**Trot (m/s)**	**Canter (m/s)**	**Canter (m/s)**
1	1.44	1.43	3.09	3.21	4.72	4.63
	1.42	1.36	3.25	3.17	4.69	4.30
	1.50	1.42	2.93	3.01	4.82	4.59
Mean	**1.46**	**1.4**	**3.07**	**3.13**	**4.74**	**4.50**
2	1.50	1.38	3.30	2.97	4.10	3.86
	1.45	1.46	3.05	3.16	4.33	3.90
	1.51	1.42	3.21	3.11	4.20	4.07
Mean	**1.49**	**1.42**	**3.19**	**3.08**	**4.21**	**3.94**
4	1.52	1.35	3.20	3.31	4.50	4.68
	1.55	1.42	3.21	3.22	4.26	4.69
	1.47	1.42	3.31	3.16	4.48	4.61
Mean	**1.51**	**1.40**	**3.24**	**3.23**	**4.41**	**4.66**
5	1.39	1.42	2.91	2.93	4.04	4.06
	1.38	1.34	2.80	2.96	3.98	4.07
	1.33	1.42	2.91	3.06	4.20	4.37
Mean	**1.37**	**1.40**	**2.88**	**2.98**	**4.07**	**4.17**
6	1.54	1.60	3.31	3.48	4.23	4.60
	1.50	1.54	3.59	3.54	4.42	4.55
	1.53	1.51	3.50	3.41	4.45	4.59
Mean	**1.52**	**1.55**	**3.47**	**3.48**	**4.37**	**4.58**
7	1.36	1.43	3.25	3.50	4.32	4.61
	1.45	1.38	3.11	3.04	4.42	4.45
	1.50	1.37	3.23	3.11	4.31	4.38
Mean	**1.43**	**1.40**	**3.20**	**3.21**	**4.35**	**4.48**
8	1.45	1.45	3.24	3.45	4.75	4.82
	1.54	1.51	3.21	3.45	4.84	4.97
	1.70	1.47	3.42	3.22	4.84	4.76
Mean	**1.56**	**1.47**	**3.29**	**3.38**	**4.81**	**4.85**
9	1.55	1.49	3.54	3.41	4.98	5.19
	1.57	1.50	3.43	3.35	5.01	5.10
	1.51	1.44	3.49	3.44	5.28	4.89
Mean	**1.54**	**1.48**	**3.48**	**3.40**	**5.09**	**5.06**
10	1.49	1.53	3.26	3.19	4.03	4.06
	1.43	1.48	3.30	3.22	4.04	4.08
	1.42	1.44	3.23	3.27	3.92	4.11
Mean	**1.45**	**1.49**	**3.26**	**3.23**	**4.00**	**4.09**

5.2.1 Hoof rotation and displacement

Hoof rotation was measured using Range of Motion (ROM) from impact to mid-stance (figure 5.2) and mid-stance to toe off (figure 5.3) in X (roll), Y (pitch) and Z (yaw). There was no significant difference (p>0.05) found between treatments (harrowed and rolled) in any plane for both ROM when tested using general linear modelling.

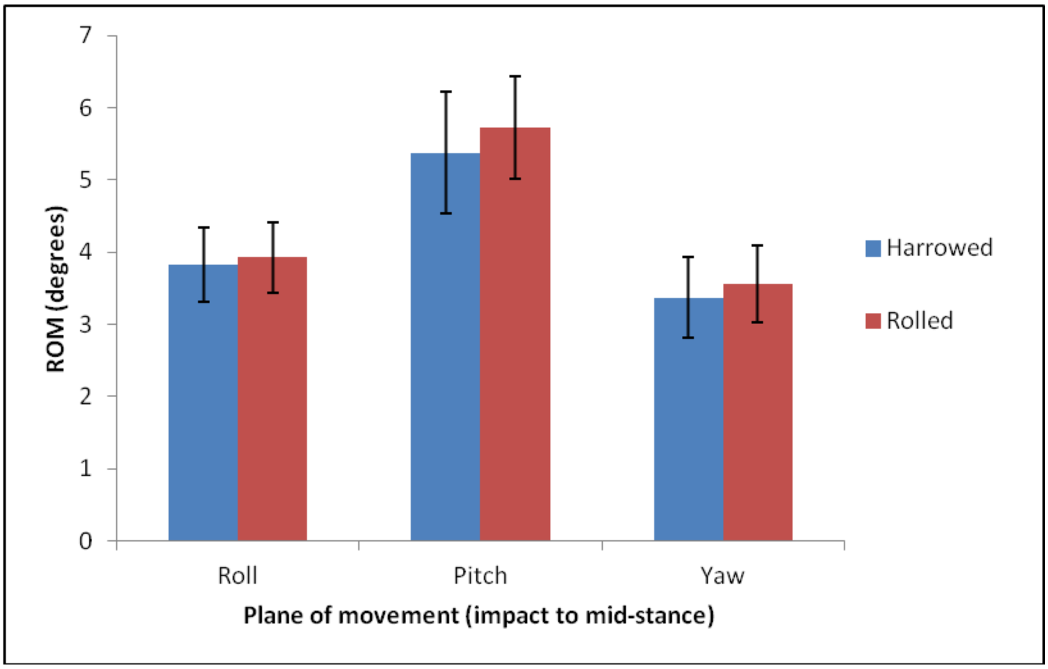

Figure 5.2. Comparison of mean (n=81) ROM in roll, pitch and yaw for impact to mid-stance between treatments (harrowed and rolled) (error bars indicate standard error of mean).

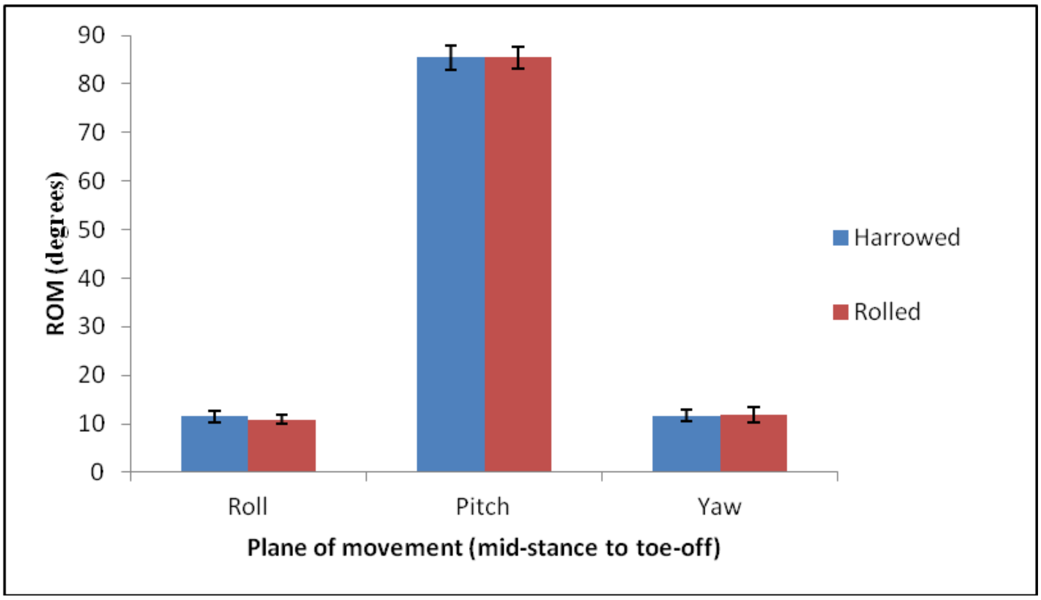

Figure 5.3. Comparison of mean (n=81) ROM in roll, pitch and yaw for mid-stance to toe off between treatments (harrowed and rolled) (error bars indicate standard error of mean).

Hoof displacement was calculated as a mean for all horses using displacement in cm from impact to mid-stance and mid-stance to toe off in craniocaudal, mediolateral and vertical directions. No significant differences ($P<0.05$) were found between the two maintenance treatments in any plane or phase of stride (Table 5.3).

Table 5.3. Mean results (n= 81) for hoof displacement (cm) ± standard error of mean, from Impact to mid-stance and mid-stance to toe for movement craniocaudal, mediolateral and vertical.

Plane of movement	Stride phase	Mean value for ROM (cm) ± SE on Harrowed	Mean value for ROM (cm) ± SE on Rolled	P value	Significant
Craniocaudal	Impact to Mid-stance	0.03 ± 0.1	0.06 ± 0.3	0.369	No
Mediolateral	Impact to Mid-stance	0.01 ± 0.1	0.01 ± 0.1	0.925	No
Vertical	Impact to Mid-stance	0.02 ± 0.1	0.02 ± 0.1	0.534	No
Craniocaudal	Mid-stance to Toe off	0.17 ± 0.4	0.16 ± 0.3	0.929	No
Mediolateral	Mid-stance to Toe off	0.03 ± 0.1	0.02 ± 0.1	0.916	No
Vertical	Mid-stance to Toe off	0.05 ± 0.1	0.05 ± 0.1	0.668	No

5.2.2 MCPJ Rotations

MCPJ extension was split into three parts for analysis; impact, mid-stance and toe off. General linear modelling was used with horse and gait variability taken into account. There was no significant difference ($p>0.05$) found in mean (n=81) MCPJ extension between treatments for impact or toe off. Significantly ($p<0.05$) greater extension was however found on the harrowed treatment at mid-stance (figure 5.4). The difference in joint angle between the two treatments was 1.07 degrees and it is important to note that this was for a mean value (n=81) that included all gaits. *Post hoc* analysis showed the largest differences between treatments for an individual gait (n=27) to be in walk and trot though this was not found to be significant (figure 5.5).

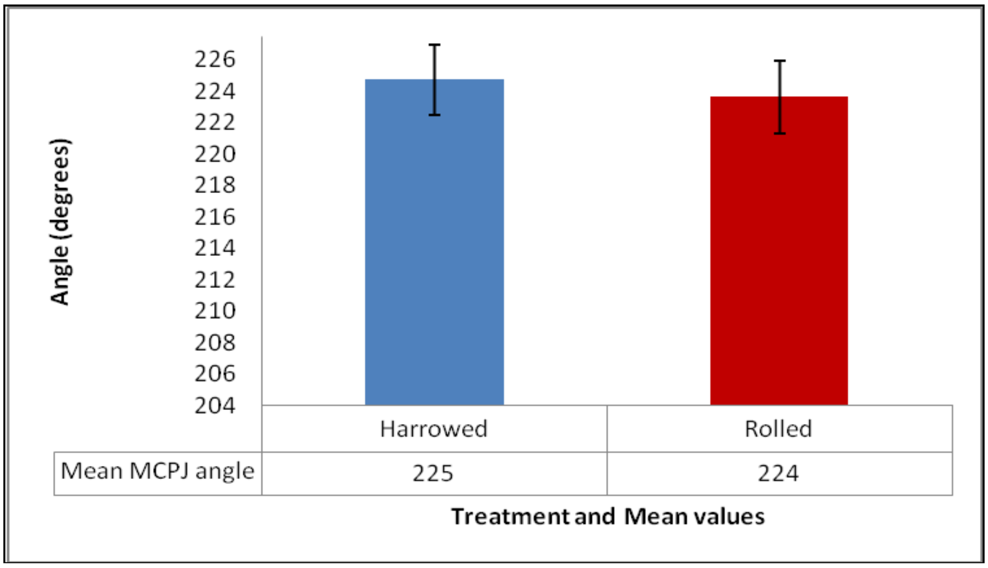

Figure 5.4. Comparison of the overall mean (n=81) angle for treatments harrowed and rolled for MCPJ extension at mid-stance (error bars indicate standard error of mean). Values on the Y Axis begin from the mean value (n=9) for all horses MCPJ extension angle when standing (204.4°).

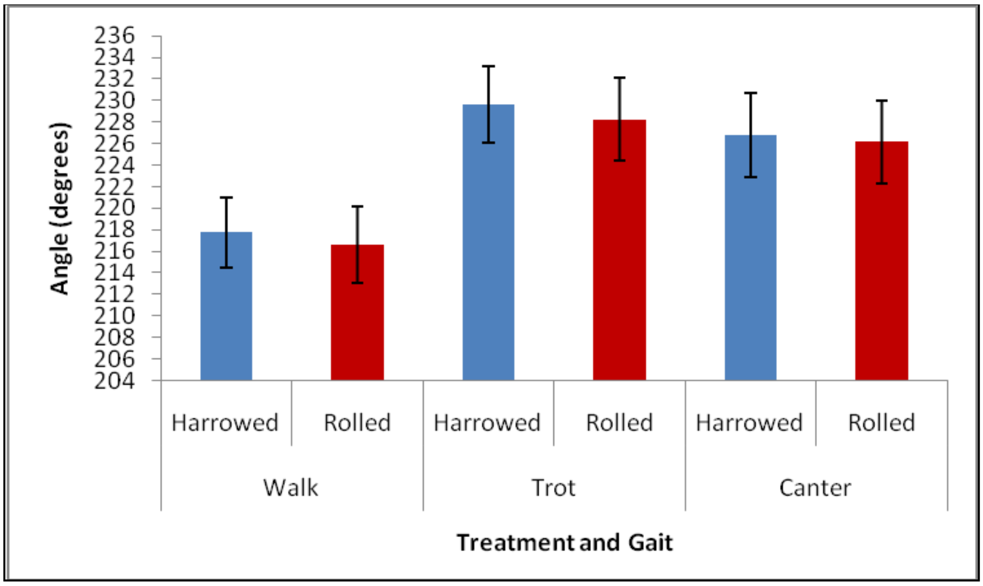

Figure 5.5. Comparison of the overall mean (n=27) angle for treatments harrowed and rolled for MCPJ extension at mid-stance split in walk, trot and canter (error bars indicate standard error of mean). Values on the Y Axis begin from the mean value (n=9) for all horses MCPJ extension angle when standing (204.4°).

5.2.3 MCIII inclination

MCIII Inclination was measured in roll, pitch and yaw at impact and toe off. General linear modelling was used with horse and gait variability taken into account. A significant difference was seen between treatments for roll at impact (p=0.04) (figure5.6) but not toe off (p=0.78). A greater amount of limb adduction was therefore found on the harrowed surface compared to the rolled at impact. It should be noted that the significant difference recorded was not subject to a particular gait. A *post hoc* analysis appeared to show however that the largest differences between treatments for a particular gait were in walk and canter (figure 5.7) but these were not proven to be significant (p>0.05).

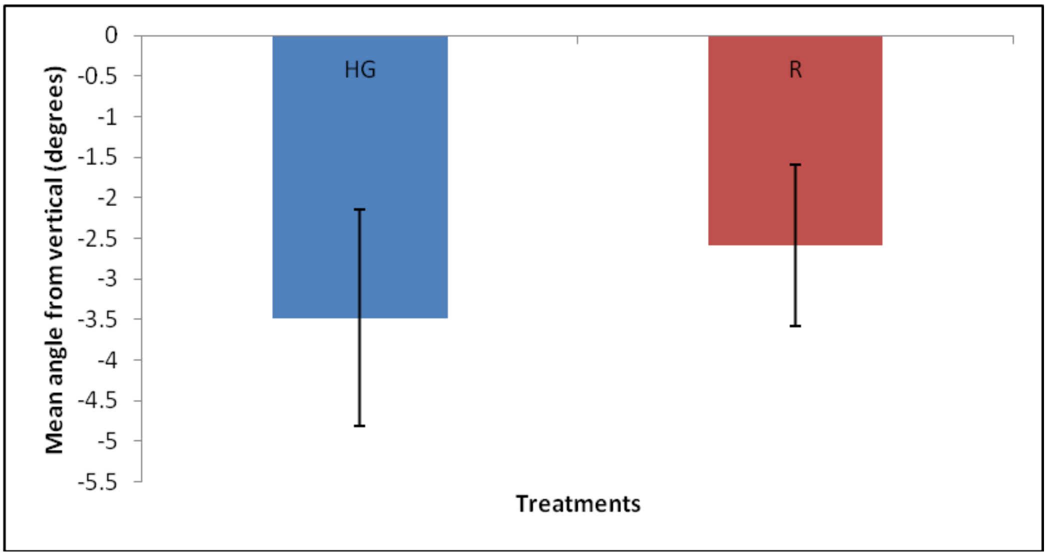

Figure 5.6. Comparison of treatments harrowed (HG) and rolled (R) for mean (n=81) MCIII Inclination in roll at Impact (error bars indicate standard error of mean).

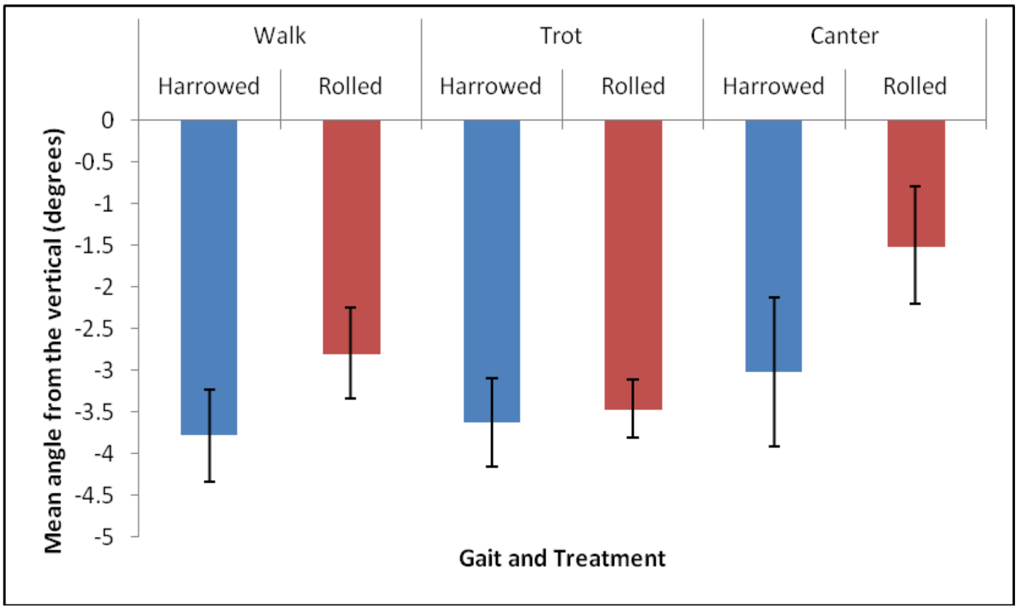

Figure 5.7. Comparison of treatments harrowed and rolled split into gait for mean (n=27) MCIII Inclination at Impact for roll (error bars indicate standard error of mean).

There were no significant differences (p>0.05) found between treatments for pitch (figure 5.8) or yaw (figure 5.9) at either impact or toe off.

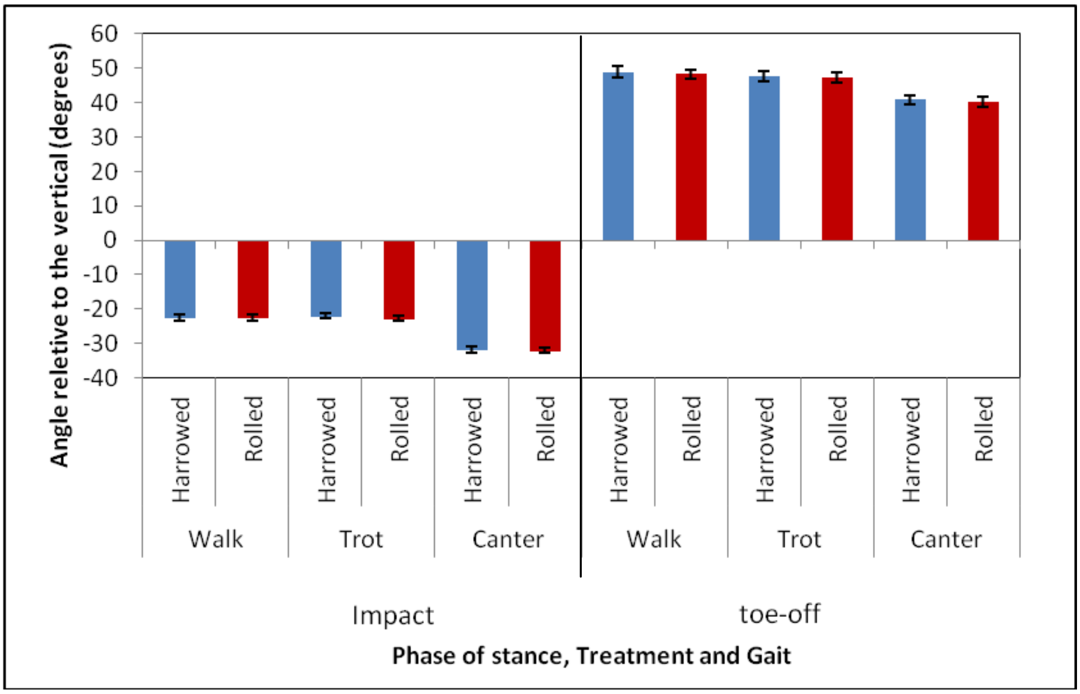

Figure 5.8. Comparison of treatments harrowed and rolled for MCIII Inclination at Impact and toe off in pitch, split into all gaits (n=27). The limb crosses the zero line around mid-stance passing from negative to positive values (error bars indicate standard error of mean).

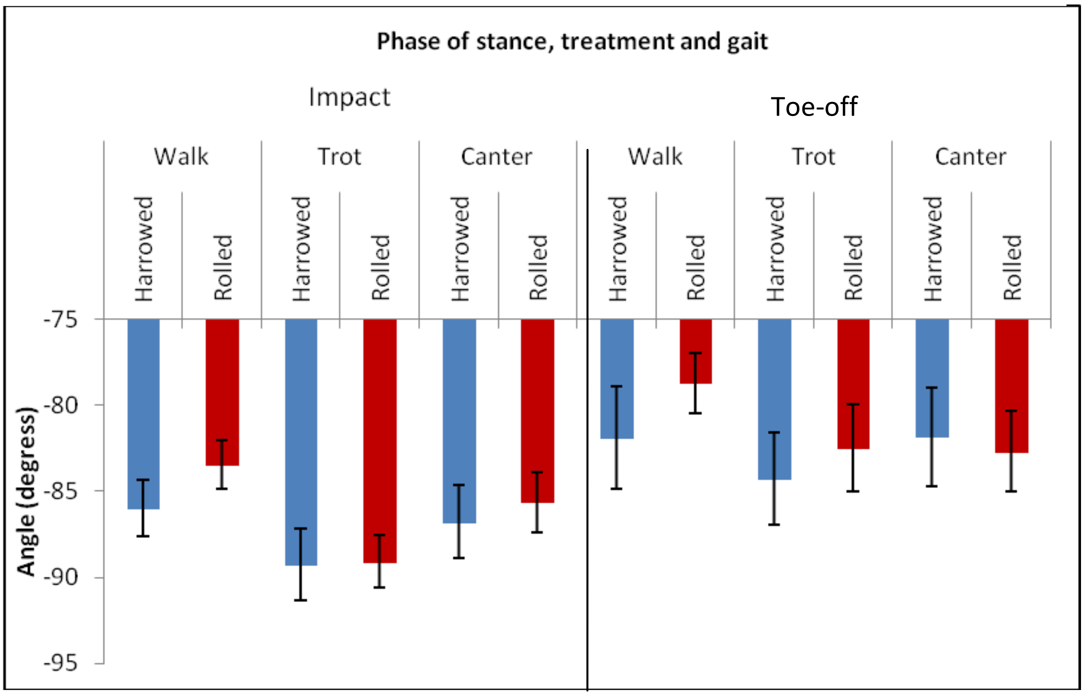

Figure 5.9. Comparison of treatments harrowed and rolled for MCIII Inclination at Impact and toe off in yaw, split into all gaits (n=27) (errors bars indicate standard error of mean)

5.3 Mechanical surface properties

5.3.1 Hardness Measurements for hardness were taken for each surface treatment after each horse. Figure 5.10 shows the difference in values for each horse on both treatments with data collected from the Clegg testing area (squares 51-65) referred to in section 4.5 (pg 32). A correlation was then performed to appraise the relationship between testing day and hardness for the track (figure 5.11). A slight trend was observed with hardness appearing to increase over the duration of testing.

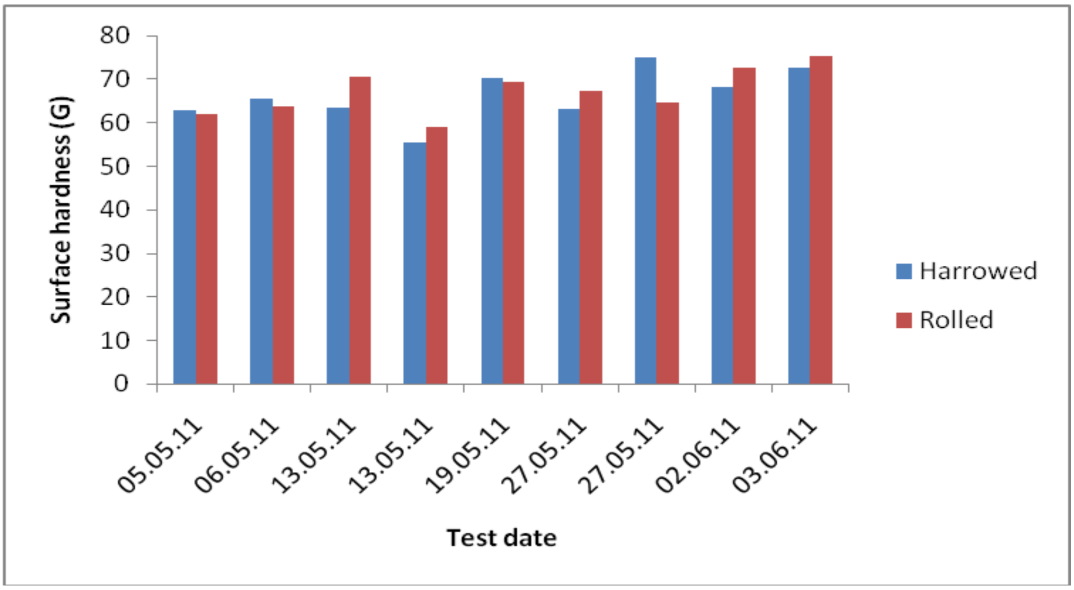

Figure 5.10. Comparison of mean (n=75) surface hardness readings (gravities) for treatments (harrowed and rolled) for each horse on each date of testing. Data was collected from the originally selected area for hardness testing (squares 51-65).One horse was tested on each date, except for the 13th and 27th May, where two were tested. Data for horses tested on the 13th and 27th May are displayed in the order in which they were collected.

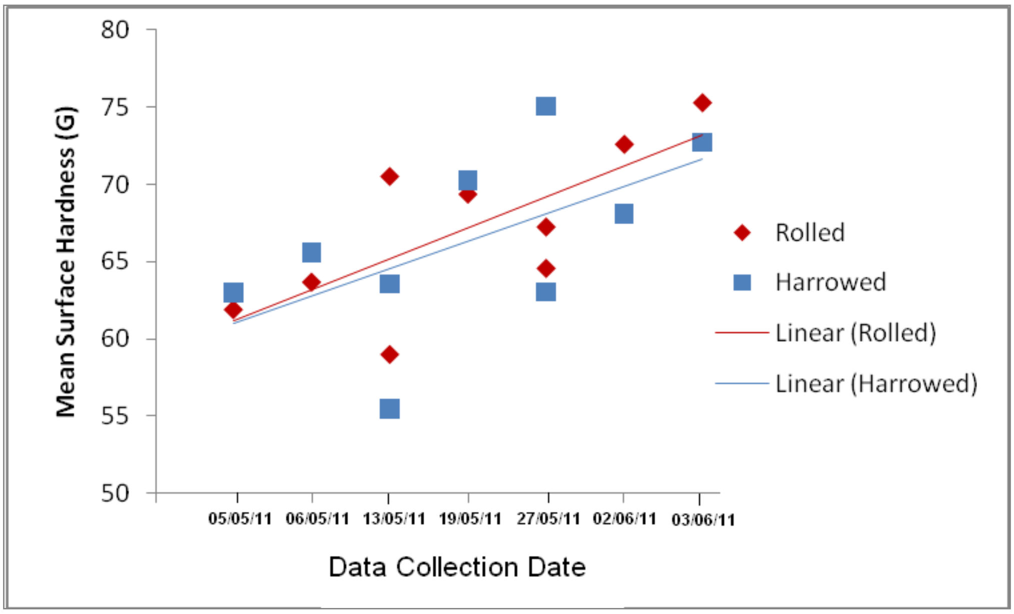

Figure 5.11. A slight trend was observed between mean hardness (n=75) and data collection date for both treatments (harrowed and rolled) on the originally selected area for hardness testing (squares 51-65).

Results for hardness were broken down further with testing squares 57-61 of the testing grid (figure 4.1, pg33) chosen to represent hardness for the study. The selection was based on the fact that the motion data was captured in that specific area resulting in it being most relevant when related to the kinematic results. The difference in values between surface treatments on the selected test area was compared for each horse as well as for over the whole of the testing period (Table 5.4). In table 5.4 the greater hardness value for each horse is highlighted in red. The difference between treatments as a whole was not shown to be significant (p=0.278). It is interesting to note however that seven out of nine trials show the rolled surface to be marginally harder than the harrowed, though only one of these produced significant results (horse 10-p<0.05). Hardness for both treatments were then correlated with testing order for the selected area (figure 5.12, pg54). Figure 5.12 demonstrates a lesser trend for an increase in mean hardness value related to test day order when compared to the track as whole and was not found to be significantly correlated (figure 5.11, pg52). The difference in surface hardness from the start to the end of testing therefore showed less change on this smaller selected area than the larger original one. Values recorded suggest this was due to the smaller area already having greater hardness readings from the start of testing compared to those found on the same dates in the larger area.

Table 5.4. Comparison of mean arena surface hardness readings (gravities) ± standard deviation, for treatments (harrowed and rolled) for each horse on each date. Values were collected from a specified area of test track (squares 57-61 of figure 4.1,pg33). For individual horses n=25, for all horse mean n= 225. Greater hardness values for each horse are highlighted in red.

Horse	Data collection date	Harrowed (mean ±SD)	Rolled (mean ±SD)	Difference	P value	Significant
1	05/05/11	63.28± 1.3	65.08 ± 4.3	-1.8	0.462	No
2	06/05/11	64.88± 2.6	64.96± 2.9	-0.08	0.956	No
4	13/05/11	67± 7.9	72.8±2.5	-5.8	0.165	No
5	13/05/11	55.8± 2.8	58.2± 2.3	-2.8	0.104	No
6	19/05/11	66.52± 4.4	67.52± 5.7	-1.2	0.474	No
7	27/05/11	67.52± 2.1	66.28± 1.7	1.24	0.455	No
8	27/05/11	73.72± 5.4	67.84± 2.8	5.88	0.129	No
9	02/06/11	66.76± 6	71.36± 1.4	-4.6	0.229	No
10	03/06/11	69.08± 3.5	73± 3.1	-3.9	0.002	Yes
All Horses (mean)		**66.07 ± 4.8**	**67.44 ± 4.6**	**-1.37**	**0.278**	**No**

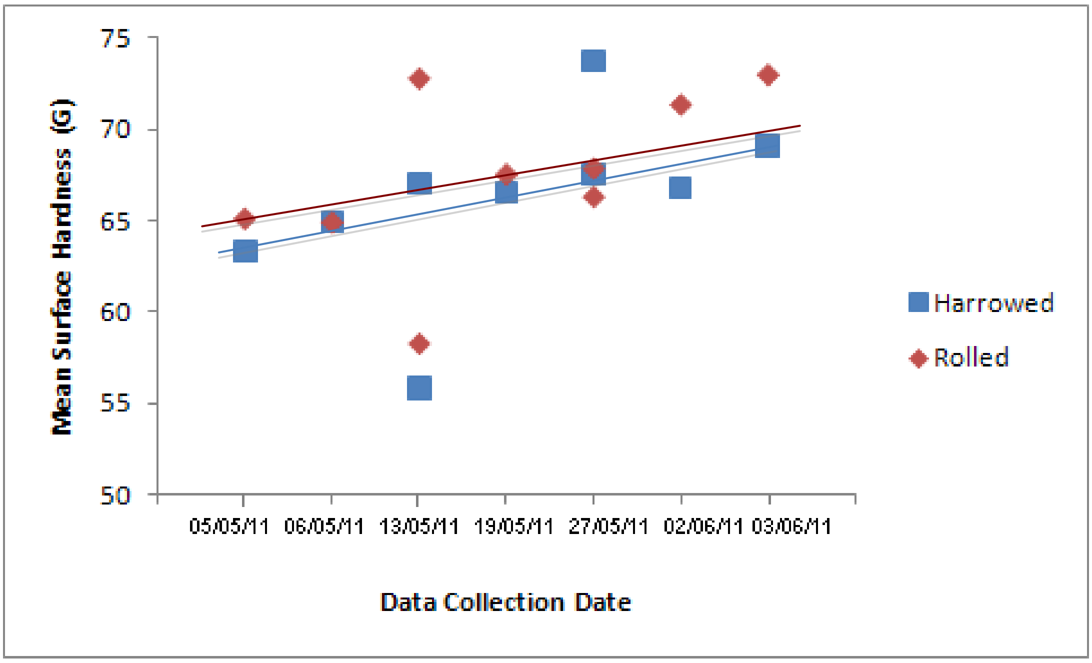

Figure 5.12. Mean hardness (n=25) for data collection date for both treatments (harrowed and rolled) on the smaller selected area for testing (squares 57-61).

5.3.2 Traction A mechanical fault with the torque wrench mechanism meant that measurements of torque were taken for each treatment after only six of the nine horses had finished the test procedure. Figure 5.13 shows the difference in values for each horse on both treatments with data collected from the original testing area (squares 51-65), as previously mentioned. Four out of six data collections showed a greater level of traction on the rolled surface compared to the harrowed. The mean results for the two treatments over the whole course of the data collection displayed a significant difference (p=0.001) with greater traction on the rolled surface.

Results were then broken down further to testing squares 57-61 using the same method outlined for hardness in section 5.3.1. There was no significant difference (p>0.05) overall between treatments on the smaller test area. Table 5.5 (pg56) shows that the rolled was found to be harder on four out of six tests, two of which were significant (p<0.05). A correlation was then performed to appraise the relationship between testing day and torque for the track (figure 5.14 pg56). There appeared to be no relationship between torque levels recorded on the surface and testing day over time.

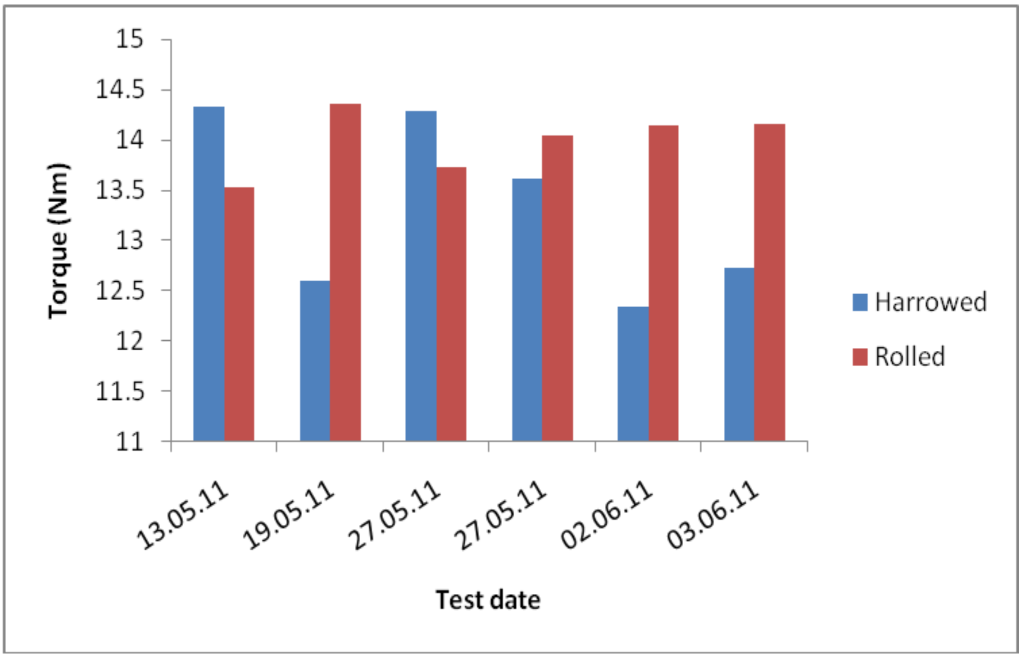

Figure 5.13. Comparison of mean (n=75) surface torque readings (Nm) for treatments (harrowed and rolled) for six out of nine horses on data collection days. Data was collected from the originally selected area for hardness testing (squares 51-65).One horse was tested per day, except for the 27/05/11 where two were tested. Data for horses on 27/05/11 is displayed in the order in which it was collected.

Table 5.5. Comparison of mean arena surface traction readings for treatments (harrowed and rolled) for each horse on each date. For individual horses n=75, for all horse mean n= 450. Greater hardness values for each horse are highlighted in red.

Horse	Data collection date	Harrowed mean±SD (Nm)	Rolled mean±SD (Nm)	Difference	P value	Significant
5	13/05/11	13.60 ± 0.7	13.28 ± 0.7	0.32	0.508	No
6	19/05/11	12.64 ± 0.5	13.44 ± 0.4	-0.82	0.053	No
7	27/05/11	14.24 ± 0.7	13.84 ± 0.3	0.40	0.387	No
8	27/05/11	13.64 ± 0.4	13.92 ± 0.4	-0.28	0.341	No
9	02/06/11	12.60 ± 0.4	14.44 ± 0.4	-1.84	0.002	Yes
10	03/06/11	12.88 ± 0.5	13.71 ± 0.1	-0.13	0.014	Yes
All Horses (mean)		**13.26 ± 0.6**	**13.70 ± 0.4**	**-0.44**	**0.202**	**No**

Figure 5.14. Comparison of mean (n=25) surface torque readings (Nm) for treatments (harrowed and rolled) for six out of nine horses on data collection dates, with data for two horses collected on 27/05/11. Data was collected from the smaller selected area for hardness testing (squares 57-61). There was no correlation observed between values ($p<0.05$).

5.3.3 Moisture content

Moisture content of the surface was determined by sampling the North and South end of the track. Figure 5.15 shows the moisture content on the testing dates for both mean (n=3) ends of the track as well as the mean average (n=6) for the two. Moisture content appeared to vary between the North and South of the track though the samples were not found to be significantly different ($p>0.05$) from each other for any of the test dates.

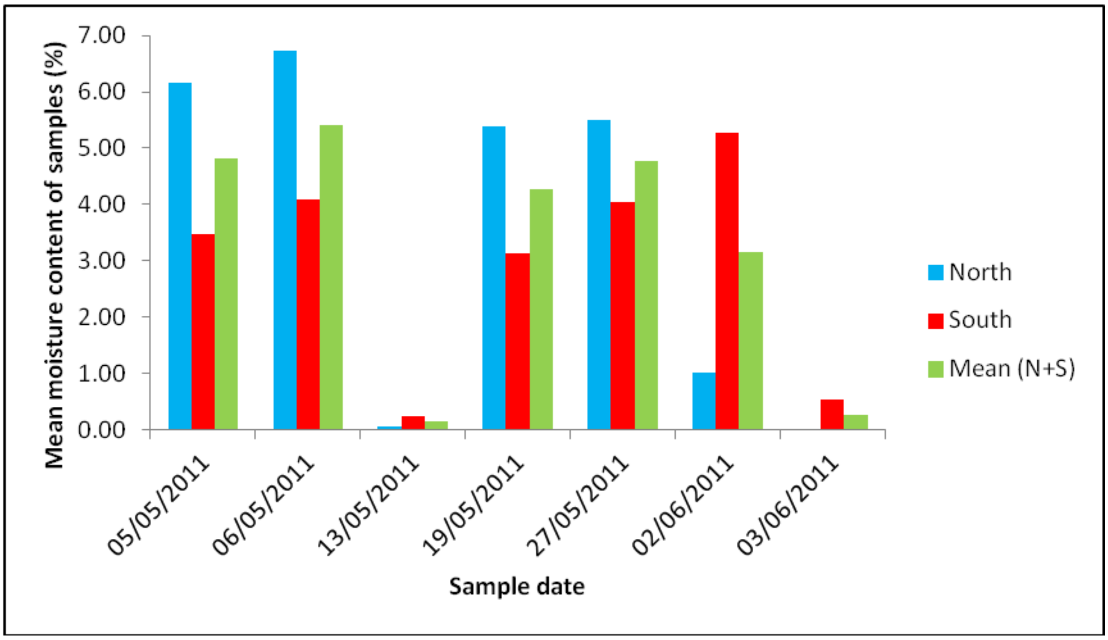

Figure 5.15 Moisture content levels of the surface samples taken from the test track on data collection dates. Samples were taken from the North and South of the track with a mean produced for each (n=3) A mean average (n=6) of the two ends was also produced to give an indication of moisture content of the track as a whole.

5.3.4 Climatic conditions Data was collected for maximum and minimum air temperatures as well as soil temperature, rain fall and humidity for all the testing dates (table 5.6).

Table 5.6. Daily temperatures, rain fall and humidity for collection dates throughout May and June 2011 at Myerscough College, Lancashire.

Date	Air temp max	Air temp min	Soil temp (10cm) 9am	Rain (mm) previous day 24hr	Rain on day (mm) 9am-9pm	Humidity %
05/05/2011	18.6	13	13.6	0	1.4	56
06/05/2011	20.9	13.8	13.8	2.8	0.2	78
13/05/2011	14.40	6.8	12.8	0	0	85
19/05/2011	15.30	9.8	12.1	0.4	0	73
27/05/2011	14.70	10.8	13.1	0.8	0	78
02/06/2011	19.80	12.8	15.1	0	0	92
03/06/2011	25.40	17.9	16.2	0	0	60

5.4 Correlations between mechanical surface properties and kinematic results

A number of correlations were performed *post hoc* to explore possible relationships between mechanical surface properties and kinematic results. Correlations were performed for hardness as well as traction in relation to the two kinematic results that had yielded significant differences between treatments; MCPJ extension at mid-stance in roll and MCIII inclination at impact in roll. Results for MCPJ extension and MCIII inclination were then correlated together.

5.4.1 Hardness correlations No significant correlation ($p>0.05$) was found between mean values for MCPJ extension and mean values for surface hardness for either harrowed or rolled (figure 5.16). There was also no significant correlation ($p>0.05$) found between values for mean MCIII inclination in roll and values for mean surface hardness for both treatments (figure 5.17, pg59).

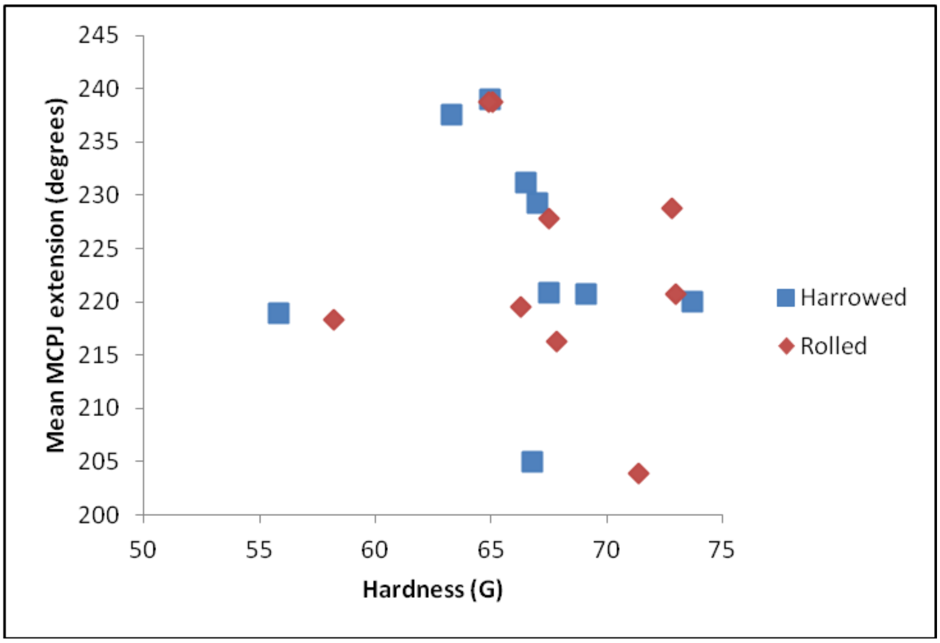

Figure 5.16. There was no significant correlation found between mean values (gait x repetition -n=9) for MCPJ extension and mean values (n=25) for surface hardness for either treatment (harrowed and rolled).

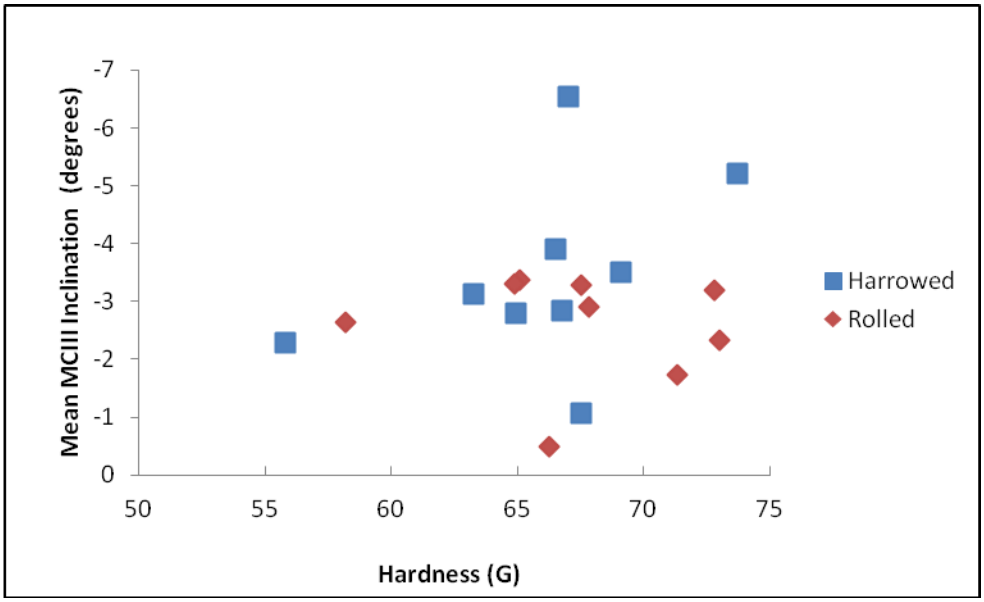

Figure 5.17. There was no significant correlation found between mean values (gait x repetition -n=9) for MCIII inclination in roll and mean values (n=25) for surface hardness for either treatment (harrowed and rolled).

5.4.2 Shear strength correlations

No significant correlation ($p>0.05$) was found between mean values for MCPJ extension and mean values for surface hardness for either harrowed or rolled (figure 5.18). There was also no significant correlation ($p>0.05$) found between mean values for MCIII inclination and mean values for surface hardness for both treatments (figure 5.19, pg 60).

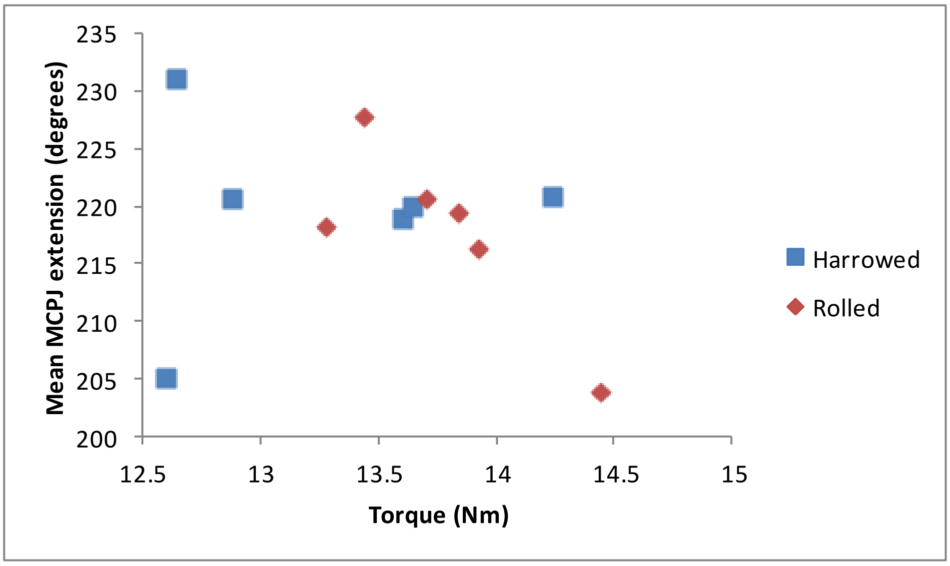

Figure.5.18. Scatter diagram for mean (gait x repetition -n=9) MCPJ extension at impact and mean (n=75) surface torque for both treatments (harrowed and rolled). There was no significant correlation found between mean values for MCPJ extension and mean values for surface traction readings for either treatment

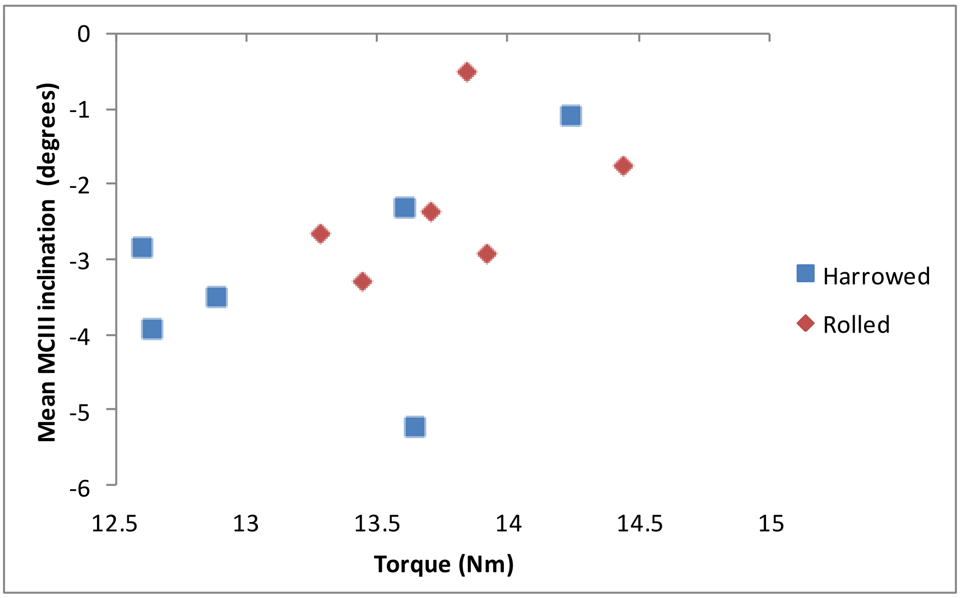

Figure 5.19. Scatter diagram for mean (gait x repetition -n=9) MCIII inclination at impact in roll and mean (n=75) surface torque for both treatments (harrowed and rolled). There was no significant correlation found between mean values for MCIII Inclination and mean values for surface traction readings for either treatment

5.4.3 MCIII inclination correlated with MCPJ extension

No correlation was found between values for MCIII inclination in roll at impact and MCPJ extension at mid-stance following either harrowing or rolling (figure 5.20).

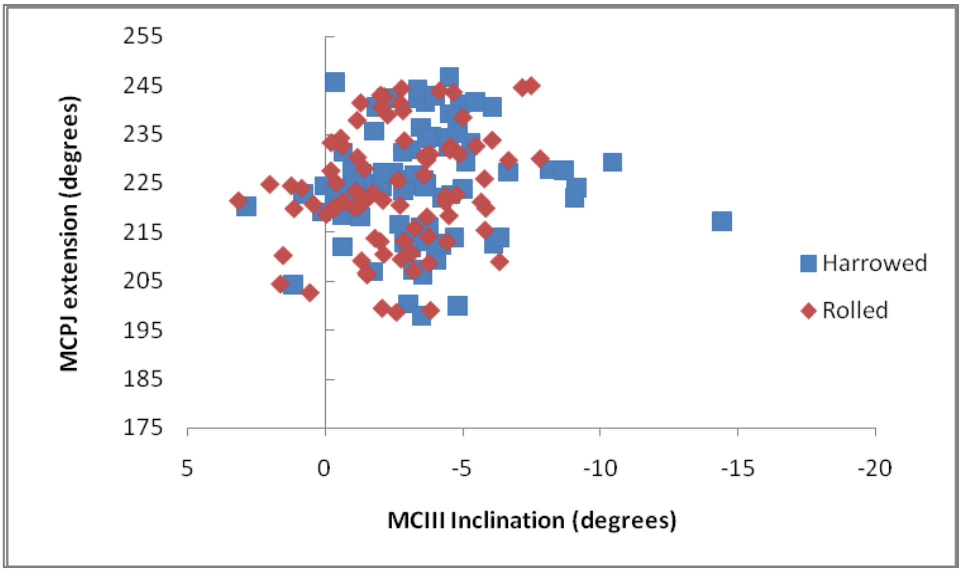

Figure 5.20. There was no correlation found between value for MCPJ extension (n= 162) at mid-stance and values for MCIII inclination in roll at impact for either treatment (harrowed and rolled).

A correlation was found between MCIII inclination in pitch at impact and MCPJ extension at mid-stance. MCPJ extension increased as pitch angle decreased on both harrowed and rolled surfaces. Figure 5.21 shows the correlation for all trials for all horses in canter. Similar trends were also found in walk and trot.

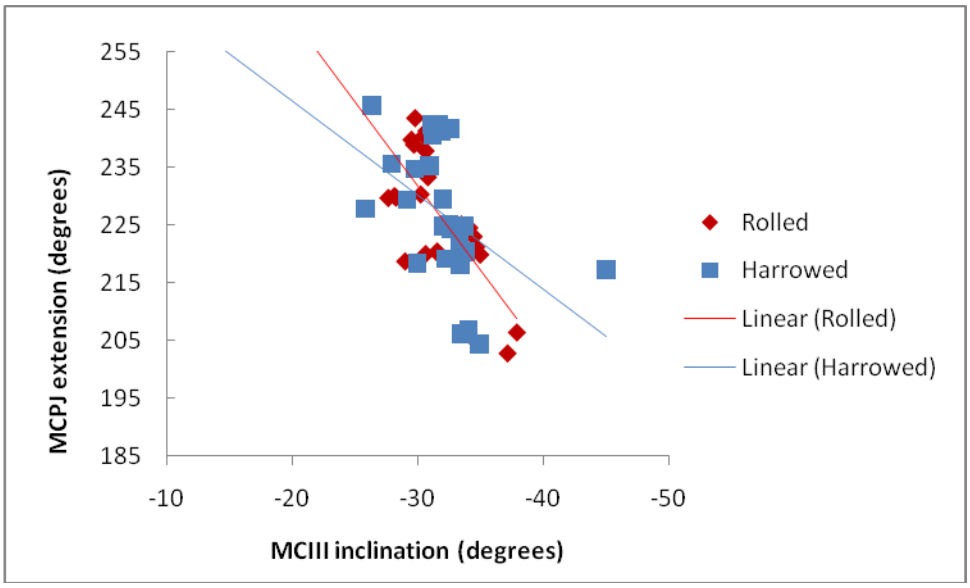

Figure 5.21. There was a correlation found between values (n=54) for MCIII inclination in pitch at impact and MCPJ extension at mid-stance for both treatments in canter (harrowed and rolled). Similar trends were found for walk and trot.

5.5 Summary of main results

The main equine kinematic and mechanical surface property results that were analysed using statistical tests are summarised in table 5.7.

Table 5.7. Results description including p value for significance. Results highlighted in red were found to show a significant difference between harrowed and rolled treatments.

Results				
Kinematic analysis	**p value**			**Significant**
There was no difference found in hoof rotation in roll, pitch or yaw for impact to mid-stance or mid-stance to toe off between harrowed or rolled treatments.	Roll Imp-mid **p=0.855**	Pitch Imp-mid **p=0.695**	Yaw Imp-mid **p=0.768**	No
	Roll Mid-toe **p=0.881**	Pitch Mid-toe **p=0.920**	Yaw Mid-toe **p=0.984**	No
No difference was shown in the amount of hoof displacement measured in cranio-caudal, mediolateral or vertical directions between harrowed or rolled treatments.	Cranio-caudal Imp-mid **p=0.369**	Mediolateral Imp-mid **p=0.925**	Vertical Imp-mid **p=0.534**	No
	Cranio-caudal Mid-toe **0.929**	Mediolateral Mid-toe **0.916**	Vertical Mid-toe **0.668**	No
No significant difference was found for MCPJ extension at impact or toe off on either treatment.	Impact **p=0.252**	Toe off **p=0.174**		No
A significant difference was found for MCPJ extension at mid-stance. Greater levels of extension were measured on a harrowed surface compared to rolled.	Roll Mid-stance **p=0.044**			**Yes**
A significant difference was found for MCIII inclination at impact in roll. Greater levels of adduction were measured on a harrowed surface compared to a rolled one.	Roll Impact **p=0.040**			**Yes**
No difference was found for MCIII inclination in roll at toe off between treatments.	Toe off **p=0.788**			No
There was no difference found in MCIII inclination in pitch and yaw at either impact or toe off between harrowed or rolled treatments	Pitch Impact **p=0.474**	Yaw Impact **p=0.070**		No
	Pitch Toe off **p=0.362**	Yaw Toe off **p=0.122**		No
Mechanical surface properties			**P value**	**Significant**
No difference was found for mean hardness between harrowed and rolled treatments on the original test area (squares 51-65).			**p=0.564**	No
No difference was found for mean hardness between harrowed and rolled treatments on the smaller test area (squares 56-61).			**p=0.278**	No
A significant difference was found for mean torque readings between harrowed and rolled treatments on the original test area (squares 51-65).			**p=0.001**	**Yes**
No difference was found for mean torque measurements between harrowed and rolled treatments on the smaller, selected test area (squares 56-61).			**p=0.202**	No

Chapter Six – Discussion

6.0 Introduction

The current study was developed to investigate the movement of the distal limb and hoof of the horse on an arena surface treated using different general maintenance procedures. There are currently no set standards or rules governing surface maintenance in any equestrian sport. Surface substrate, moisture content and design have all been studied to ascertain the relationship they each have to injury and performance (Barrey *et al.,* 1991; Chateau *et al.,* 2009; Gustås *et al.,* 2006a; Murray *et al.,* 2010a; Peterson and McIlwraith, 2008; Setterbo *et al.,* 2011). Studies documenting race track characteristics (Dallap-Schaer *et al.,* 2006; Peterson and McIlwraith, 2008; Ratzlaff *et al.,* 2005) and related injury (Parkin *et al.,* 2004a,b,c; Williams *et al.,* 2001) have benefited all disciplines by identifying areas of significant importance in the aetiogenesis of such problems. It is essential therefore that surfaces used for equine training and competing in non-racing disciplines are also given thorough consideration by researchers.

Recent literature has widely documented that certain surface substrate characteristics can predispose horses to acute catastrophic, as well as chronic degenerative, injuries (Peterson *et al.,* 2011; Murray *et al.,* 2010a,b; Weishaupt *et al.,* 2010). It has become recognised that material consistency of a surface is of great importance to counteract issues arising from usage and climatic conditions (Murray *et al.* 2010a; Peterson *et al.,* 2011; Riggs, 2010; Setterbo *et al.,* 2011). Maintenance procedures could potentially produce a more consistent, safer surface. The amount of research work published in this area however is still lacking in comparison to that detailing other factors affecting surfaces, such as the effect of decreasing substrate hardness. Previous studies on this subject have reported the effect of treatment on mechanical surface properties without comparison to kinematic or kinetic data (Setterbo *et al.,* 2011). It is therefore essential that non-racing specific, innovative research work is carried out with a focus on maintenance that is reliable in providing mechanical as well as biomechanical information. The current study aimed to meet this research need.

Data was analysed with gaits grouped together as well as individual gaits of walk, trot and canter. It is important to understand some of the characteristics associated with individual gaits when analysing the kinematic results. Individual gaits can be defined as specific coordinated movement of the limbs that results in progressive motion (Barrey, 2001). Walk is a four beat symmetric gait that has long overlap time between the stance phases of the different limbs. The MCPJ is not extended as far in walk as it is in trot and canter due to these long cross over stance times distributing the body weight of the horse more evenly over the limbs. Trot is also symmetrical but is a two beat gait that consists of moving linked diagonal pairs. Canter, unlike walk and trot, is an asymmetrical gait consisting of three beats. In canter a leading and trailing fore limb can be identified. The leading and trailing limbs will handle loads differently due to variations in inclination and distribution of body weight (Back *et al*., 1997).

The current study investigated the effect that two different standard maintenance procedures (harrowing and rolling) had on the biomechanics of the hoof and distal limb. An infrared camera system was used to collect motion data from retro-reflective markers placed on the horses. Hardness and traction data of the surface were also collected following both treatments. Results were assessed to explore the effect the arena treatments had on the characteristics of the substrate and consequently the movement of the horse.

To carry out the study a suitable marker set for capturing 3D motion data had to be identified and validated. Kinematic values obtained were comparative with those reported by other authors. MCPJ extension values in walk (217°), averaged between treatments, agreed with those suggested by Vilar *et al*. (1995) (216°) and Smith *et al*. (2002) (216°). Values measured in trot (228°) in the current work were also similar to those that Vilar *et al.* (1995) suggest to be commonly reported (225°). Smith *et al.* (2002) states that a value of 228° is often reported for MCP extension of the leading limb in canter, again this is a similar result to that found in the current work (226°). Further to this the final marker arrangement used in this study was found to measure increases in extension of the MCPJ to the same magnitude as the currently used 2D set. The result of this validation meant that data could be taken and interpreted for all three dimensions with reassurance of its validity.

6.1 The effect of maintenance treatments on equine kinematics

6.1.1 Rotation and displacement of the hoof

The hoof is the point of contact between the horse and the surface. Incorrect rotation or displacement of the hoof is implicated in the development of injury, especially during intense competition. Hoof rotation and displacement were measured during the current study as ROM from impact to mid-stance and mid-stance to toe off, in roll, pitch and yaw for both treatments.

There was no difference found between treatments for rotation of the hoof in roll, pitch or yaw from impact to mid-stance or mid-stance to toe off. To the author's knowledge there is no published data regarding the effect of commonly used maintenance treatments on hoof rotation. On a compliant substrate, such as the synthetic one used for this study, the hoof deforms the surface as it rotates during the different phases of stance. The heel is initially reported to sink, followed by forward toe rotation from mid-stance through to break over (Chateau *et al.,* 2005; Johnston and Back, 2006). Ratzlaff *et al.* (1993) reported pitch angle of the hoof on a dirt track in galloping horses, stating acute angle values (6-7°). The current study reported ROM for hoof rotation, unlike the work by Ratzlaff *et al.* (1993). Measuring and reporting accurate absolute angles for hoof rotation using adhesive markers requires radiographs to identify the centre of rotation for the coffin joint as well as the long axis of the coffin bone relative to the hoof. The current study did not use radiographs for ethical and practical reasons meaning that an absolute angle would be an estimation and would really only produce useable values in pitch. It is more difficult to record exact angles for roll and yaw when using an estimated marker set as they are greatly affected by limb adduction. Using ROM therefore allowed direct comparison between the magnitude of movement seen in rotation in a given direction between surfaces due to the cross over design of the study methodology. Work by Chateau *et al*. (2006b) compared the effect of different shoeing procedure on ROM in the hoof on a treadmill. Comparing the results from the current study against those of Chateau *et al.* (2006b), using matched gait (walk) and phase of stride (impact-mid-stance) in standard steel shoes, the harrowed treatment appears to have produced the most similar result. The present work recorded a ROM of 3.6^{o} (±1.7) on the harrowed treatment and 5.2^{o} (±1.7) on the rolled (figure 5.2, pg47). Chateau *et al.* (2006b) however reported a backward rotation of 5.1 ^{o} (±3.8) for impact to hoof stabilisation and then a forward rotation of 1.3^{o} (±1.9) from hoof stabilisation to heel off in standard shoes. Significance was not found in separate gaits in the current study, though this may have been influenced by sample size. All motion results in the current work were tested using a mean value that included data from walk, trot and canter. The mean (±SE) ROM found for pitch was 5.3^{o} (±4.3) following harrowing and 5.7^{o} (±3.6) for rolling, resulting in no significant difference between treatments at impact to mid-stance (figure 5.3, pg 47).

It is suggested by Peterson *et al.* (2008) that when studying surface characteristics it is deformability that has the largest influence on limb and hoof kinematics. The current study focused on the effect that two general maintenance treatments would have on the mechanical properties of one synthetic surface. The ability of the surface to deform after maintenance treatments was estimated in the current study by comparison of kinematic values in relation to hardness and traction values. It should be noted however that the surface deformation is affected by the physical properties and composition of the surface and not just the treatment it receives. Factors such as these must therefore be considered.

Hoof rotation is suggested to give a reliable indication of a surface's ability to deform during the stance phase of the gait (Johnston and Back, 2006). Harrowing an equine arena surface is thought to lead to a decrease in substrate hardness and shear resistance and therefore should produce an increase in substrate deformation (Setterbo *et al.,* 2011; Thomason and Peterson, 2008). Conversely rolling a surface is reported to lead to decreased deformation through increased hardness and shear properties. It could be expected therefore that in the current study harrowing the test track would produce a softer surface cushion resulting in an increased hoof rotation and displacement when compared to the rolled treatment. Mean hardness for the whole test period however was not significantly different between treatments. The lack of difference between treatments for hoof rotation could to some extent be explained by this finding. Statistically neither treatment resulted in a cushion layer that was harder than the other. Such results imply that neither procedure allowed for greater rotation in any direction at any point of the stride as mechanically they were identical in terms of ability to deform through hardness.

It is anecdotally suggested that synthetic surfaces, especially those with a wax content, require currently undetermined levels of loading to allow them to settle and to some extent compact. The test track had been laid for four months prior to commencement of testing and had undergone no use aside from the validation work involving maintenance treatments. Data was collected on seven dates between May and June of one year with horses spending relatively minimal time on the track. The addition of an untreated control area to the current study may have enabled identification of normal settling behaviour of the substrate. The ability of maintenance procedures to actively treat the surface cushion during this stage could have then been analysed. It may be that neither treatment has a notable effect on hardness at this settling stage due to the less compact nature of newly laid synthetic sand and wax surfaces.

The surface was however found to be significantly different between the two treatments in terms of torque with greater levels found on rolled although this was only on the larger original test area. The smaller selected area within the filming zone showed no difference between treatments for torque. Peterson *et al.* (2011) reports that at toe off specifically it is the surface's resistance to shear that determines rotation of the hoof. This information would explain the lack of difference seen in hoof rotation at toe off in the current study as torque in the filming zone was not altered. The area for filming was subject to greater levels of human and equipment traffic as well as equine. The extra loading of the surface possibly proved to have a greater effect on the mechanical substrate properties, such as torque, than the maintenance equipment did.

As well as hoof rotation, no difference for hoof displacement in craniocaudal, mediolateral or vertical directions, from impact to mid-stance or mid-stance to toe off was found between treatments. A small amount of craniocaudal slippage, especially at impact, is beneficial to the horse and aids in decreasing forces encountered during deceleration. Too much however can be damaging to the supporting systems of the joints of the limb (Orlande, 2009). The amount of displacement and rotation of the hoof can vary due to surface substrate characteristics (Gustås *et al.,* 2006b; McClinchey *et al.,* 2004). The potential for displacement of the hoof has been identified as being greater on asphalt, rubber and concrete than sand (McClinchey *et al.,* 2004). Information such as this suggests that traction of the hoof is higher on rougher materials, providing they are firm. The current study found traction levels to be statistically non-different between treatments within the filming area, which would explain the lack of difference recorded for craniocaudal and mediolateral hoof displacement. Further to this, Burn (2006) suggested that on sand surfaces hoof penetration depth (vertical) can affect displacement (craniocaudally) due to the force exerted on the hoof wall by the surrounding substrate. Hoof penetration (vertical) ROM did not alter between treatments in this study, and as suggested by Burn (2006), neither did craniocaudal displacement. The likely reason for this result is again that hardness and therefore possible deformation of the surface was not changed between treatments.

The present study used the same surface material for both treatments but hypothesised that the mechanical properties would alter once treated with either a harrow or roller. In the specific filming area neither hardness nor traction changed significantly, which would explain the lack of difference seen for hoof displacement between treatments. Research is therefore recommended comparing hoof displacement in all directions in relation to varying hardness and traction levels to explore the related effects. The importance of hoof slip and rotation cannot be overlooked as it will directly influence movement of the limb and accompanying joints.

6.1.2 Extension of the MCPJ and MCIII inclination

Extension of the MCPJ has been previously described as a passive event caused by the vertical forces placed upon it (Johnston and Back, 2006). Extension of the joint is resisted by supporting structures such as the SDFT, DDFT and the SL (McGuigan and Wilson, 2003; Smith *et al.,* 2002). Strain in these structures is therefore highly dependent on the angle of the MCPJ. In the stance phase of the gait the weight of the horse will cause extension of the joint with maximal values reached around mid-stance (Clayton, 1997). The level of MCPJ extension is influenced by factors such as age, velocity, weight, surface and gait.

The results from the current study found mean MCPJ extension to be no different between treatments for either impact or toe off. Extension of the MCPJ during stance phase is directly related to substrate hardness with greater values reported by other researchers on harder surfaces (Clayton, 1997; Heaps *et al.,* 2011; Smith *et al.,* 2002). The results for MCPJ extension at impact and toe off therefore support this theory as neither treatment was proved to result in a significantly harder surface.

Mean MCPJ extension at mid-stance however was greater on the harrowed surface (225°) compared to the rolled surface (224°) when gait was grouped. Breaking the MCPJ data down into gait showed that larger values were produced for extension following harrowing than rolling for all separate gaits; walk (218° vs. 216°), trot (229° vs. 228°) and canter (226° vs. 225°). Vilar *et al.* (1995) reported findings from a personal communication from Martinez, which suggested average acute MCPJ extension angles of 218° in walk and 226° in trot at mid-stance. The values for both gaits are identical to those found for the harrowed surface in the current study, although the surface on which they were collected is not stated. Kicker *et al.* (2004) used a 3D marker set to record dorsiflexion angles, which equate to palmar angles of 224° in walk and 237° in trot on a treadmill. Values for both gaits are greater than those recorded during the current work but this is possibly to be due to the harder nature of the treadmill surface in comparison to a wax synthetic substrate. Smith *et al.* (2002) states typical peak angles in canter to vary between limbs with 228° for the leading limb and 238° for the non-lead. The current study measured extension of the MCPJ of the leading limb in canter and reported similar though slightly lower values.

Mid-stance is the main weight bearing phase of the stride where the limb acts as a supportive strut and the body passes over it. Maximum joint extension is therefore expected around this point. A harder surface, due to its lack of deformation during this increased moment of weight bearing would cause greater extension of the MCPJ. The study hypothesized that the rolled surface would become harder than the harrowed and therefore greater levels of MCPJ extension would be recorded, but this was not the case. Neither treatment yielded a harder surface than the other; therefore the difference reported could be caused by other factors. Gait, velocity, collection, supporting structure strength, shoeing and surface have all been reported to alter extension of the joint (Chateau *et al.,* 2006a; Clayton, 1997; Heaps *et al.,* 2011; McGuigan and Wilson, 2003; Smith *et al.,* 2002). The current study was designed with these issues in mind as the only influence the study aimed to investigate was that of the surface in relation to MCPJ extension. A cross over design was used for the study meaning that horses were compared to themselves for opposing surface treatments thus negating issues surrounding difference in natural gait patterns. All horses were shod in steel shoes on all four hooves, with none undergoing any type of remedial farriery that would involve shoes designed to adjust natural movement of the horse. As the horses acted as crossover for each treatment the effect of one horse having different shoes would have been unlikely to have affected the overall results. Velocity was controlled throughout the trials by use of a tracking marker placed on the sternum of each horse and followed using Qualysis track manager. Velocity was recorded and analysed in field during testing to ensure each horse was velocity matched across treatments. A *post hoc* analysis found no significant difference ($p>0.05$) between velocities on either a harrowed or rolled surface in any gait for each horse. Ratzlaff *et al.* (1995) reported that horses show a set preference for stride rate at a given gait and velocity, suggesting that stride length would also be maintained. Chateau *et al.* (2010) however reported that horses did alter stride length in relation to surface substrate. Although stride length was not specifically measured in this work a change in stride length would lead to a change in inclination of MCIII in pitch. No significant difference was found for MCIII inclination in pitch suggesting that horses not only keep a constant velocity but exhibited no change in stride length on either surface. Velocity and stride length were therefore not producing the greater MCPJ extension values seen following the harrowed treatment. A number of *post hoc* analyses were therefore conducted to attempt to identify the cause.

There is a strong relationship between the body's centre of mass and the magnitude of loading that the limbs receive (Buchner *et al.,* 2000). It was found during *post hoc* analysis that at impact and mid-stance the sternum marker, and therefore the horses' body, appeared further forward over the limb on the harrowed surface than on the rolled. The MCPJ could consequently have been under increased loading, which would explain the higher levels of extension found on the harrowed treatment. The trend for a more forward body position and related increase in extension values, was observed in the majority of trials for all gaits and all horses. Further *post hoc* analysis showed that there was a strong correlation between MCIII pitch inclination at impact and MCPJ extension at mid-stance on both surfaces (figure 5.21, 61). As pitch angle decreased MCPJ extension increased and this was true for both treatments. The difference between treatments for mean MCPJ extension was 1.07° when all gaits were grouped (figure 5.4, pg 49). Significance was not found when testing for individual gait, though figure 5.5 (pg 49) in the results does show greater MCPJ extension following harrowing in walk, trot and canter. The effect on MCPJ extension caused by harrowing is therefore subtle but it is significant ($p<0.05$) and should not be overlooked. Harrowing is possibly causing small alterations to the surface cushion that are not large enough to elicit a change in hardness or traction but are enough to cause the horse to display altered stride kinematics.

MCIII inclination in roll, pitch and yaw is used by researchers to identify the placement of the limb in relation to the body (Chateau *et al.,* 2006a; Hobbs *et al.,* 2011). The study found no difference in MCIII inclination for pitch or yaw at impact or toe off (figures 5.8 and 5.9, pg 51). A horse will modify its pattern of locomotion in relation to substrate properties (Chateau *et al.,* 2010; Clayton, 2002; Weishaupt *et al.,* 2010b). Chateau *et al.* (2010) reported horses to alter stride length and stride frequency greatly between extremely different surfaces (asphalt and deep dry sand). The current study only used one surface but applied two treatments that were hypothesised to alter the mechanical properties of the substrate and therefore possibly the stride characteristics. Hardness and traction was the same for both treatments within the filming area which is possibly why pitch and yaw inclination were not altered.

A significant difference was found for MCIII inclination at impact but not toe off in roll. The results show that the limb was adducted to a greater extent on a harrowed surface compared to a rolled one. Mean adduction of the limb for all gaits was -3.5° on the harrowed surface and -2.6° on the rolled (figure 5.6, pg 50). A trend was seen for greater adduction following harrowing compared to rolling for each gait when split into walk (-3.8° vs. -2.8°), trot (-3.6° vs. -3.5°) and canter (-3° vs. -1.5°) (figure 5.7, pg 50). There is currently no information available regarding inclination of the limb in relation to surface maintenance procedures. Surface inclination has however been shown to influence limb inclination. Hobbs *et al*. (2011) reported significantly larger levels of adduction of the MCIII on a flat surface than a banked surface on a turn. The authors presented the results for adduction as positive values with results in trot on a banked turn (7.2°) most similar to those reported as negative values in the current work (-3.6°). This figure still shows larger levels of adduction than those found in the present study and this is most likely due to the alteration of foot placement and body inclination needed to negotiate a 10m circle. This is supported by the fact that the study found MCIII inclination values to be larger for the inside leg than the outside. The work by Hobbs *et al.* (2011) does however ever demonstrate that the horse will alter placement of the hoof relative to the body and that this will affect limb adduction. Differences in velocities between studies may also have influenced levels of MCIII adduction with greater speeds recorded in the study by Hobbs *et al.* (2011) (3.58m/s) than those found in the current work (3.24m/s).

In the current study a trend was seen for greater adduction following harrowing compared to rolling in walk, trot and canter (figure 5.7, pg 50). Analysis of trials in Visual3D™ illustrated the difference measured for MCIII adduction between treatments in the majority of trials in all gaits for all horses (plate 6.1). It appears that the horse is altering the swing phase of the gait and this in turn is affecting the stance phase due to a change in foot placement in the frontal plane. It is possible therefore that had absolute angles and not ROM been reported for hoof rotation a difference may also have been found.

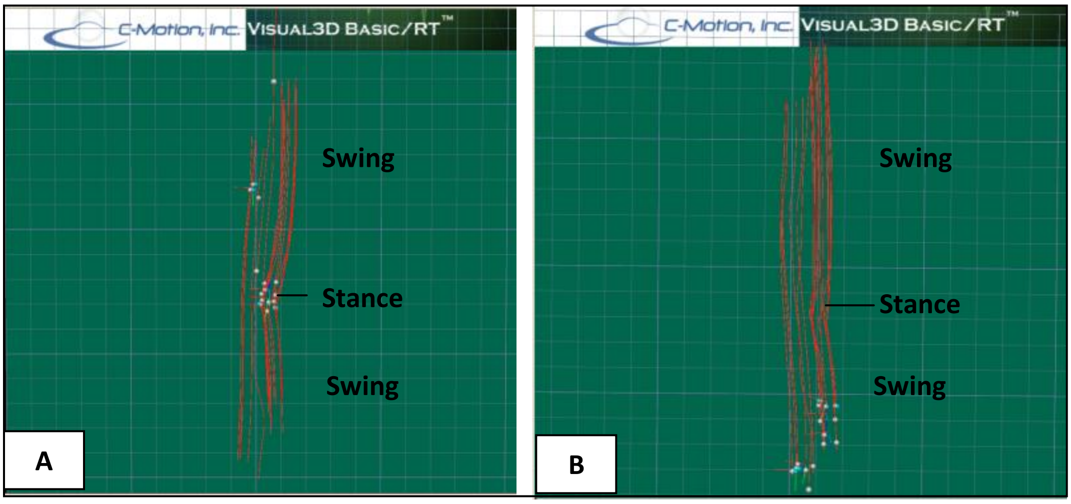

Plate 6.1. MCIII adduction images taken from Visual3D™. Greater levels of adduction were seen following harrowing of the surface (A) compared to rolling (B). The left forelimb analysed in this study is shown on the right of the two plates. The red lines trace the marker patterns of motion of the limb and hoof.

Results from MCPJ extension already suggest that horses in the current study were exhibiting significant differences in stride kinematics due to possible perceived differences caused by surface treatments. The change in level of adduction of the MCIII between treatments strengthens the idea that locomotion patterns were altered due to small differences in surface characteristics. Barrey *et al.* (1991) reported the damping effect of a track to be dependent on particle size distribution and density. It is possible that the treatments in the current study altered the cushion layer of the track sufficiently enough to produce differences in shock acceleration and vibration frequency felt by the horse. Previous studies have measured such impact characteristics successfully using accelerometer or specially adapted force shoes (Chateau *et al.,* 2009; Gustås et al 2006b; Hjerten and Drevmo, 1994; Ratzlaff *et al.,* 2005; Robin *et al.,* 2009). Forces such as these were not measured in this study so the changes seen cannot be directly attributed to them although it could explain such subtle changes as those recorded. Further work investigating the effect of different surface treatments in relation to gait alteration could lead to a greater understanding of the effect maintenance procedures had on mechanical surface properties and therefore equine kinematics.

6.2 Mechanical surface property results

Data for hardness and traction was recorded during testing to attempt to assess possible characteristics of the surface that could affect the motions found in the hoof and limb. Hardness data was collected using a Clegg hammer, a piece of apparatus that has undergone extensive testing and use in human, and more recently equine, sports surface research (Caple *et al.,* 2011; Malmgren *et al.,* 1994; Popke, 2002; Setterbo *et al.,* 2011). The Clegg hammer can however only give an approximation of the possible vertical forces encountered by the horse. A torque wrench was therefore also used to partially address some of the opposing forces, in this case traction, often considered in terms of shear force. The study used a specially adapted torque wrench constructed to replicate a shod hoof. The torque wrench accomplished this using a custom-made base plate fitted with a standard type steel horse shoe. Neither piece of apparatus could however measure ground reaction forces and should therefore be used as a guide to the possible forces encountered by the horse.

There was no significant difference found between mean hardness for rolled (67.1G) versus harrowed (66.3G) treatments over the study period on the originally designated test plots. It was found that five out of nine days resulted in larger hardness readings after use of the roller, compared to four out of the nine for the harrow (figure 5.10, pg 52). No trend was seen regarding treatment order, time of day, air or soil temperature or moisture content of the track, in relation to either the harrow or the roller. Overall mean hardness was relatively low on both treatments when compared to previous work. Fidler (2008) reported mean hardness to be 90G following rolling of a synthetic arena surface to and 73G following harrowing. Further to this work, Blundell *et al.* (2010) reported hardness readings ranging from ~70 to ~90G for a synthetic sand and rubber surface. Setterbo *et al.* (2011) suggests that additives to sand surfaces, such as fibres, rubber and wax, cause the substrate to behave differently compared to sand alone in relation to equipment measuring mechanical properties.

A slight trend for an increase in hardness was seen over time (in relation to date of testing), independent of treatment. Loading of a substrate over time is the most efficient manner in which to get it to settle as mentioned in section 6.1.1. It is therefore possible that measurements for hardness were influenced by an amount of shifting and settling of the substrate. *Post hoc* analyses were therefore run to investigate possible relationships between hardness, traction, treatment and test dates on a smaller area of the track specific to the filming zone that had received the most loading. Further to this it was felt that this specific area would yield results that were more relevant to the kinematic data recorded due to being directly within the filming zone. No significant difference was found for hardness or traction between treatments for the selected test area. The trend for an increase in hardness over time that had been found on the larger test area was not found on the smaller one. The length of the track and the sharp turns to enter and exit meant that this middle section, which was the filming zone, was the only area to be trotted and cantered on. The smaller area was subject to traffic from not only horses, but researchers and vehicles as well. The reduced correlation between hardness for both treatments and test date could therefore be caused by an increase in traffic to the area resulting in a more settled surface although this still seemed to have no measurable effect on readings recorded after maintenance treatments. A study conducted after a greater time period in which the track had been ridden on and regularly maintained would build on results found in the current work. It is possible that the settling of a surface is affected by moisture levels and due to the outside location of the track used in the current work moisture could not be controlled.

A significant difference was found between treatments for traction using the specially adapted torque wrench on the originally selected test area. A greater amount of traction was found on the rolled treatment (14.00Nm) as opposed to harrowed (13.28Nm). Peterson and McIlwraith (2008) support this finding reporting shear strength to be reduced on a harrowed surface compared to a non harrowed surface. Results from the smaller test area however found traction to not be significantly different following treatments, with 13.26Nm recorded following harrowing and 13.70Nm following rolling. Both these results are slightly lower than those seen for the larger test area but are also lower than that reported in work by Fidler (2008) that found traction on a harrowed sand surface to be 21.2Nm and 23.Nm on rolled. Peterson and Mcilwarith (2008) suggest that the shear strength of a dirt surface is perhaps not affected by standard maintenance procedures due to clay in the track having the greatest bearing on cohesive properties. It is possible that adding wax to a sand substrate produces the same effect in synthetic surfaces.

The moisture content of the surface is cited as being one of the most influential factors on mechanical properties of a substrate due to its influence on surface hardness and therefore injury risk (Parkin *et al.,* 2004a; Peterson *et al.,* 2011; Ratzlaff *et al.,* 1997). No water was manually added to the track at any point, meaning the level the surface received was weather dependant. It is also important to note that the synthetic surface tested contained wax and that the track was laid on a special drainage system containing permavoid units. Adding wax to a sand surface increases its ability to retain water in hot dry conditions as well as conversely enabling it to show improved drainage in very wet conditions (Murray *et al.,* 2010a). The permavoid units are designed to act as a moisture management system, increasing the moisture retaining ability of a surface, and there is currently no research available on the suitability of use of this technology in regard to synthetic equestrian surfaces. The present study did not aim to address the effect these units had on substrate character or horse kinematics. Future work monitoring the effect that such technology has on current understanding of surface characteristics is however a priority.

The current study found the moisture levels to fluctuate by between 1-5% on different testing days as well as sampling sites across the surface. Generally however moisture levels did appear to be reduced over time with the exception of the third testing date. Samples were taken from the north and south of the track and presented in the results as separate values as well as a mean for the two. The mean minimum moisture content of the surface on one day was recorded at 0.1% and the mean maximum at 5.4%. A report by Peterson *et al.* (2011) regarding moisture in racetracks supports these findings, stating that levels in the cushion fluctuate across a surface, even if levels in the base are found to remain constant.

Barrey *et al.* (1991) suggested a moisture content between 8-17% of a wax-free sand surface aids in deceleration of the hoof at impact. Levels for the current study were all below the minimum 8% recommended by Barrey *et al.* (1991) however the substrate tested in the present work contained wax. Synthetic surfaces containing wax are widely used in racing and non-racing disciplines. In England top equestrian competitions such as The Horse of the Year Show have chosen to use this type of substrate. Recommendations for moisture levels of synthetic surfaces with a wax content would therefore be a valuable development in relation to suggested maintenance procedures. It is vital that researchers continue to explore the relationship between these mechanical surface characteristics and the effect they have on the movement of the horse.

The values produced in the study bring into question why the hardness and traction of the surface in the selected test area did not alter in response to either treatment applied. It has been reported (Setterbo *et al.,* 2011) that the magnitude of changes seen for surface hardness and deformation when harrowed are directly related to the depth that the tines penetrate the surface. The current study used a joint harrow and grader with spring tines that are designed to aerate the surface (Andrews Bowen, 2011). When compared to harrow levels tested by Setterbo *et al.* (2011), the treatment applied in the current study would be best defined as a shallow harrow (2-5 cms deep), affecting the top of the surface. At initial hoof impact it is this top loose layer of the track that quickly becomes compressed. The stiffer pad level below the cushion then becomes instrumental in carrying the load of the horse from secondary impact through to toe off. Ratzlaff *et al.* (1997) found that extensive harrowing of a sand and clay track to the depth of 6cm had minimal effect on the deeper layers of the track other than inadvertently compacting them due to the weight of the equipment used. Further to this Setterbo *et al.* (2011) reported that harrowing a synthetic track elicited smaller changes in the mechanical responses in comparison to dirt surfaces even at the lower depths. The Clegg measures the hardness of the top surface layer on the first drop, assessing the hardness of the stiffer pad layer on subsequent drops in the same position (Peterson *et al.,* 2011). The current study used a number (5) of repeated drops, meaning the top cushion layer that the harrow had actually interacted with, was only truly measured on the first drop. Hardness results from the current study suggest that using a shallow level harrow is perhaps not sufficient to elicit measureable changes to the mechanical properties of a synthetic surface. A deeper harrow that interacts with the stiffer pad layer may be necessary to obtain a change in substrate behaviour. It is important to note however that changes brought about by such techniques are not always beneficial. Peterson and Mcilwraith (2008) found that use of a pavement ripper that cut into the surface to a depth of 15cm, reduced peak loading of the hoof but subsequently resulted in a greater standard deviation of the load. An increase in variability such as this is regarded as a possible hazard and it is unlikely that a horse will be able to constantly adapt and handle inconsistent forces.

It is important to note that the current work was undertaken to assess the effect that commonly used maintenance equipment had on a surface. The current lack of guidelines regarding suitable maintenance procedures and equipment for arena surfaces means that it is often the manufacturers' advice that dictates the treatment used. The equipment used in the current work was chosen following telephone interviews with surface manufacturers regarding suggested maintenance regimes (Appendix E). Results from this study are therefore directly applicable to the current situation in the equine industry. The level of harrow used for this work should therefore not be over looked but possibly investigated in a different manner for example following a set regular treatment over time.

Findings for hardness and traction therefore do not lead to a clear conclusion regarding the change in mechanical surface properties after preparation of a surface by harrowing or rolling. The author suggests that given the results produced, a control area undergoing neither treatment may have proved beneficial when attempting to understand factors affecting the surface. An untreated area such as this would enable researchers to monitor the settling effect of the substrate over time. In addition to this work, exploring the depth and amount of harrowing necessary to elicit recordable changes in an infield environment would prove most beneficial in answering some of the questions raised here.

6.3 Conclusion

The study focused on the effects that commonly used arena maintenance treatments had on the mechanical properties of a substrate and the movement of the horse. There are at present no set standards or regulations governing surfaces in relation to maintenance procedures necessary to maintain the optimum health and wellbeing of the horse. Research regarding horse and ground interaction has until recently focused mainly on racehorses and therefore race tracks. The author of the current study therefore decided to investigate behaviour of surfaces that were non racing specific. A test track was constructed to act as an arena and a synthetic wax surface was used.

The main study found there to be no difference in hoof displacement or rotation between a harrowed or rolled surface. Surface hardness and traction within the filming zone were not significantly altered between treatments and this is believed to have had the greatest effect on the movements of the hoof. Greater levels or altered type of treatment application may be necessary to elicit measurable changes in hoof motion. Extension of the MCPJ at mid-stance was found to be significantly greater on the harrowed treatment than rolled leading to the rejection of the original study hypothesis. *Post hoc* analysis revealed that at impact and mid-stance the sternum marker, and therefore the horses' body, appeared further forward over the limb on the harrowed surface than on the rolled. The MCPJ could consequently have been under increased loading, which would explain the higher levels of extension found on the harrowed treatment. Inclination of MCIII was used in the study to identify placement of the limb in relation to the body. MCIII inclination in roll showed significantly greater adduction of the limb on a harrowed compared to rolled surface. Horses have been shown to alter stride kinematics in relation to perceived differences in shock vibration in surfaces. It is possible that alterations to the surface cushion are enough to elicit small changes in stride characteristics. The difference in MCIII adduction shows that foot placement in the frontal plane changed which is likely to have been caused by an altered swing phase.

It is important to consider that due to the outdoor location of the surface, daily temperatures and moisture content may have also been having subtle effects on the mechanical substrate properties recorded.

The study has found that harrowing and rolling synthetic arena surfaces may be enough to produce subtle changes in extension of the MCPJ and Inclination of the limb. Such changes may also be detectable in hoof movement if acute angles are reported instead of ROM.

Further work is necessary to explore how much and what type of treatment is necessary to elicit such alteration in stride kinematics. Further research in this area could build on findings from the current study to aid researchers in understanding possible effects stride adaptation mechanisms may have on welfare as well as performance.

Chapter Seven – References

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Appendix A – Study Ethical Consent

REFERENCE NO. _______________

FACULTY OF SCIENCE

APPLICATION TO ANIMAL PROJECTS COMMITTEE FOR APPROVAL OF RESEARCH PROJECT

This form should be completed for all **NEW** applications for University research support and submitted to the Chair of the Animal Projects Committee.

Does project require a Home Office Licence? NO

Is there a licence holder? YES/NO Who holds it___________ Personal Licence no: __________

Date: 11/01/11

Investigation of different equestrian surfaces and their effects on the horse's movement during flat work and over jumps

Name of researcher and co-workers:

Laura Dagg, Alison Northrop and Sarah Hobbs
Emma Blundell; Andy Owen; Jaime Martin; Charlotte Brigden

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

<u>Aim 1</u>: The primary aim of the research is to investigate fetlock angle and limb inclination of both leading and trailing limbs, muscle activity, acceleration of the hoof and vertical force and hoof pressure under the top surface during flat work and jumping. Flat work will include walk, trot and canter. Jump work will involve clearing heights of up to 1m. One horse will be used for this initial work.

<u>Objective 1</u>: Fetlock angle and limb inclination will be measured using markers and up to ten cameras for 3D motion analysis. Activity of the superficial digital flexor and deep digital flexor muscles will be measured using wireless surface electromyography (EMG). An accelerometer will be attached to the hoof wall to collect data regarding deceleration forces for flat and jump work. Force on jump landing will be assessed using an RS scan pressure mat underneath the arena surface.

<u>Aim 2</u>: The secondary aim is to assess the horse's movement during flat work and jumping over different surfaces and surface preparations. The work will compare the horse's movement to the use of a biomechanical hoof tester. The jump height is likely to be 1-1.4m and varying width according to the horse's capabilities.

<u>Objective 2</u>: The research team will compare measurements taken of ten horses (measurements seen in aim 1) and a biomechanical rig (the Orono Biomechanical hoof Tester). Following this initial work, the team will assess different equestrian surfaces and surface preparations using the suite of tests above.

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):

Before collection of data, consent will be gained from the owners of the horses used as well as from the riders participating in the study using appropriate consent forms (attached). The horses will be checked for soundness, and the consent form will ensure the horses regularly jump at the required level. The work will take place at Myerscough College and will involve some indoor and some outdoor work, weather dependant. All researchers involved in the study will have completed the specified yard induction at the college prior to commencement.

In addition, pilot testing will take place in the Biomechanics Laboratory at UCLan to test the set up and functioning of equipment prior to data collection at Myerscough College. Specifically, the RS Scan mat will be validated for use under an arena top surface by comparing data from the mat to data from the force platform when enclosed in a protective cover and under a 150 mm depth of arena surface. Testing will be carried out with human participants and the landing from a 60 cm raised platform recorded. Verbal information about the test and written consent together and capability to undertake the study (PARQ) will be gained from all participants. Consent and PARQ forms are also attached. Other equipment (accelerometers, surface EMG electrodes and motion capture with active markers will all be tested together to ensure correct functioning and synchronization.

<u>Habituation</u>

All horses used in the study will be familiarised to the markers for measuring fetlock angle and limb inclination as well as the EMG sensors and the accelerometer before commencement of the study. Familiarisation will involve designated competent handlers applying the necessary equipment to the horse in a secure environment, the stable initially and then in an enclosed area if the horse responds appropriately. This will mean that the researchers can be confident that the horse is comfortable moving with the equipment on. Markers will be applied with an adhesive tape to specific points of the distal limb (the third metacarpal, fetlock joint and first phalanx) and checked for adhesiveness as well as possible irritability. These markers have been used regularly before with no evidence of irritation but a skin patch test will be carried out for each horse. Markers will be applied to specified points on the limb to allow measurement of limb inclination. EMG sensors shall then be attached to specified muscular regions (superficial digital flexor and deep digital flexor) by being placed inside a protective pouch of material which is then attached to the horse with use of a waterproof surgeon's

tape (skin patch tests also carried out for each horse). Surface EMG electrodes do not cause any pain and areas for application will be shaved prior to use and cleaned with ether to improve adhesiveness in a manner previously described by Robert *et al.* (2000). The accelerometer will be attached to the hoof wall and placed in a protective cover to avoid damage to equipment should the hoof strike a pole during exercise. Initial familiarisation will be carried out using a heart rate monitor and a behavioural assessment. Heart rates averaging > 180bpm for > 5 minutes will be removed from the study as a heart rate above this is classed in the category 'high intensity and hard physical stress' (Janzecovik *et al.,* 2010). Heart rate should therefore not exceed this level for this time frame with the most rapid fall being seen immediately following exercise (Snow, 1987). Continued signs of discomfort and negative behaviours (over the familiarisation period) will mean that the horse will be removed from the study. Negative behaviours are described below:

Ears pinned back, head raised, head turned, head tossed, head shaken, head down, excessive defecation (Kaiser *et al.,* 2006), threatening, ceasing forward movement, rearing, kicking, biting, lunging toward handlers, avoidance of handler and avoidance of riders aids (McGreevy *et al.,* 2009).

<u>Trial work;</u>

Aim 1 will involve work with one horse to ensure all the equipment is working effectively and that the data can be collected. Aim 2 will use up to ten horses once the equipment has been agreed. Trial work will either be split into flat and jump days with all the equipment tested at once (as set out in the guide below) or may involve different pieces from the equipment list being tested on different days with flat and jump work in one shorter session. The decision regarding the option chosen will depend on horse and rider, equipment and arena availability. All measurements will be taken with an aim to be able to collect data that can be used in future work for comparison with the Orono Biomechanical Hoof Tester (OBHT).

Aim 1 - Work will be carried out to enable the team to check the horse has been suitably habituated to the equipment and that it works correctly and provides suitable information for future work. The horse will be prepared in a suitable environment (stable) for the testing by a competent handler who is experienced with the equipment being used and the procedure that is to be followed. The horse will be tacked up and a heart rate monitor will then be fitted to the horse and the skin markers will be applied on the third metacarpal, fetlock joint and first phalanx to allow for measuring of fetlock joint angle. The surface EMG sensors will be applied to proximal muscle regions which have previously been shaved and had ether applied to clean them thoroughly. Sweat proof surgeons tape and a specially made material pouch will be used to hold the EMG equipment securely in place. The accelerometer will then be attached to the hoof wall along with a suitable covering to protect it which will wrap around the hoof wall but not interfere with the horse's natural movement. The horse will then be led to the international indoor arena where testing will take place. The rider will be wearing suitable riding clothes and protective equipment as stipulated by Myerscough including a

riding hat up to current safety standards (BSEN1384 or PAS 015). The horse will be walked in hand for a short period of time so its reaction to moving whilst wearing the equipment can be judged. Once the rider and researchers are happy with the equipment causing no problems to the horse or its movement the rider will warm the horse up. After a specified 15 minute warm up period equipment such as the accelerometer and EMG sensors can be activated and tested for their ability to collect the necessary data. Once the researchers are happy that the equipment has been sufficiently tested the horse can be warmed down and put away. If the equipment does not work as expected the researchers can work with it to try and address the problem within a suitable time frame for the horse, so it is not left standing in the arena or equally being overworked. The horse will be wearing a heart rate monitor throughout the pilot studies and if its heart rate is deemed to be too high (>180 bpm) the equipment shall be removed and the horse will be suitably warmed down. Researchers will also use behavioural observation to assess the horse's way of going and behaviour throughout this process and work will be halted if the horse is deemed to be presenting any negative behaviours. Negative behaviours will include excessive tail swishing or feet stamping, refusal to work, flight behaviours and evasive behaviours (McGreevy *et al.,* 2009) as listed earlier. The rider will also be asked how they feel the horse is during this work. The rider will know the horse well and would be able to identify abnormal behaviour as a secondary measure to ensuring the horse is comfortable with what it is being asked to do. Once researchers are happy with this phase of testing, further work will be carried out on the flat and over jumps. If researchers are unhappy with this phase of testing then possible solutions to problems that have arisen can be discussed and further flat work planned.

Aim 2 – The horses will be fitted with the desired equipment in the same procedure as was carried out for aim 1 and in the habituation work. The horses will initially be walked in hand to the arena and then ridden at walk, trot and canter to warm up. The horse will work over poles on the ground in trot and canter so to guide the horse to the specific area where the RS Scan matt will be situated and suitably covered by the arena surface. Once the horse has been ridden in walk trot and canter over the specific areas the pole will be built into a cross pole and finally an upright which will be gradually raised to meet the desired height (1-1.4m) with some variation in width as agreed by the rider and researchers. The rider will help to decide a suitable warm up/warm down and when to increase the height of the fence. Data will be collected in walk trot and canter and over a jump after the warm up. One researcher will be responsible for observing the horses to assess the behaviour throughout this process and work will be stopped if the horse is deemed to be presenting any negative behaviour continuously over a five minute period (see initial work). The rider will also be asked how they feel the horse is during this work as a secondary measure to ensuring the horse is comfortable with what it is being asked to do.

<u>Camera set up –</u> The desired camera set up has already been previously tested by the research group to ensure that the equipment is used correctly and effectively on testing days. A total of 10 cameras will be used for the jump work to capture the approach, take off, body trajectory over the jump, landing and departure of the horse. Horses will be habituated to the camera set up by being walked, trotted and then cantered through the

line of cameras as part of the warm up work. Calibration will involve use of a 3D calibration stick and wand, which will be recorded and verified prior to the horse entering the arena and data collection commencing.

<u>Surface preparation</u> – Initial work will involve preparing the surface in a number of ways. Harrowing, rolling and grading will be used and the researchers will experiment with the best methods and machinery available to them to get the desired surface finish. Surface work will take place in the indoor and outdoor arenas at Myerscough College as well as the newly built outdoor test track.

<u>Confidentiality</u> - Data collected from the study work will remain entirely confidential and anonymous. The information provided by the riders and horse owners via consent forms ensures eligibility for taking part in the study. Information on the horse and rider involved as well as written consent will be stored safely and securely and will not be available to any third parties. The rider will sign a consent form (attached) and a ParQ participant form.

<u>Cut off point</u>

In the unlikely event that the horse is used for up to 2 hours in any one testing session, a break will be enforced for 1 ½ hours before commencement of the work. Show jumpers would be expected to work up to 2 hours in general management.

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

One *Equus caballus* will be used for the initial study. Ten horses (*E. caballus*) will be used for the main trial.

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?

The horses used in the study will be kept in regular work involving a mixture of flat and jumping. The cost to the horse is therefore minimal as it will be asked to perform at a level it is regularly used to doing. Heart rate will be measured to look for signs of stress during habituation and if it is >180bpm over a five minute period or the horse is seen to

show signs of lameness at any point it will removed after warming down appropriately. A behavioural assessment will be carried out as an additional measure of stress (as indicated in part 2). The horses chosen will be selected in the knowledge that they regularly jump heights that will be asked of them.

The use of biomechanics in athletic performance enhancement, therapeutics and sports medicine is becoming more predominant in the equine industry (Clayton, 2004). The effect of body trajectory over a jump in relation to fetlock angle and inclination of leading and trailing limbs is yet to be fully studied and understood. The use and adaptation in research of specialised equipment such as motion analysis software, EMG and accelerometers is however becoming well established. The results from such studies will aid in the understanding of the relationships between the horse and surface during work. This work will, in the long-term help to reduce injury and therefore increase welfare in the horse (Morris and Lawson, 2009).

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 study causes minimal cost to the horses involved as they will already be fully familiarised with the equipment being used, in a safe and enclosed environment. The heart rate and behaviour of the horses will be measured throughout the habituation process and behaviour and health will be of utmost importance throughout the trial work. These observations will be (primarily) carried out by the lead researcher.

The horses will be at a suitable fitness and experience level to comfortably perform the tasks asked of it without causing undue stress or over work. The height of the fence has been judged to be within the study horse's particular capabilities ensuring the projects validity. The horses chosen will be ones that routinely carries out this type of work for 1-2 hours in a day. The horses chosen will also be used to people observing them during exercise.

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

There is no scope for reduction of the number of horses used in the initial study as it will consist of only one horse. The results from this initial study allows the main work, to follow the principles of the three Rs (Schuppli *et al.,* 2004) when finalising numbers for the further study work. The possible application of results gained from the study validates the work being carried out. The results will help to understand the impact that a surface has on the way a horse moves. Ultimately this will lead to improvements in the arena surface and therefore reduce the risk of injury.

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.

The use of just one horse for the pilot will be suitable to test the equipment and for the type of information necessary. Using one horse will also allow the researchers to work within time constraints and validate ideas for the second aim and will, in the long-term aim to help reduce injury in competition horses in relation to surface properties. The work will help researchers to understand the effects that the surface maintenance and properties have on the way the horse moves and ultimately educate the industry by increasing awareness of appropriate surface preparations for equestrian surfaces.

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Appendix B –Risk Assessments

MYERSCOUGH COLLEGE

RISK ASSESSMENT TITLE	PROGRAMME AREA	ASSESSMENT UNDERTAKEN	ASSESSMENT REVIEW
Habituation for Testing on 22nd December	Equine	**Signed: L. A. Dagg** **Date: 01/03/10**	**Date:**

STEP ONE	STEP TWO	STEP THREE
Positioning reflective markers: horse may be startled by procedure; horse may bite, kick, stand on, or knock into handler.	The researchers and horse are at risk	The researchers have undergone Myerscough College yard safety training in the past. Both the researchers have experience with horses. The horse will be safely restrained with use of a head collar and a lead rope tied with an emergency escape knot to bailing twine. If the horse becomes upset and pulls back the twine will snap and not injure the horse. The skin markers will be applied in the horses stable, the co-worker will be handling the horse and the researcher will be applying the anatomical markers to specified areas on the body. A patch test will be done before all the markers are applied to make sure that the horse does not have an adverse reaction to the adhesive. The researcher will ensure that she is aware of her body position to the horse in case the horse decides to kick out. The researcher will be

		wearing a suitable riding hat. The riding hat must be up to standard, PAS 015/BSEN 1384 or equivalent. Researchers will also be wearing other PPE including appropriate clothing, sturdy footwear and gloves.
Attaching some tape to the hoof wall of one of the horses front feet: horse may bite, stand on, kick or knock into the handler or researcher.	The researchers and horse are at risk.	The researchers have undergone Myerscough College yard safety training. Both the researchers have experience with horses. Both the researchers have experience with horses. The horse will be safely restrained with use of a head collar and a lead rope tied with an emergency escape knot to bailing twine. The tape will be applied to the horses hoof in the stable; the researcher will ensure that she is aware of her body position to the horse in case the horse decides to kick out. The researcher will be wearing a suitable riding hat. The riding hat must be up to standard, PAS 015/BSEN 1384 or equivalent. Researchers will also be wearing other PPE including appropriate clothing, sturdy footwear and gloves
Attaching two objects of similar weight and size to an EMG sensor to the horse: horse may bite, stand on, kick or knock into the handler or researcher.	The researcher and horse are at risk	The researchers have undergone Myerscough College yard safety training in the past. Both the researchers have experience with horses. The horse will be safely restrained with use of a head collar and a lead rope tied with an emergency escape knot to bailing twine. The objects used will be free from sharp corners and possible irritants and be deemed safe by the researchers. The objects will be secured to the skin in the area of the deep digital flexor muscle and superficial digital flexor muscle of one of the front limbs; the researcher will ensure that she is aware of her body position to the horse in case the horse decides to kick out or becomes startled. The researcher will be wearing a suitable riding hat. The riding hat must be up to standard, PAS 015/BSEN 1384 or equivalent. Researchers will also be wearing other PPE including appropriate clothing, sturdy footwear and gloves
Putting the horses bridle on with the tension gauge in place on one of the reins: the horse may become frightened	The researchers and the horse are at risk	The researchers have undergone Myerscough College yard safety training. Both the researchers have experience with horses. The researchers will first make sure that the stable is clear of anything that the horse could injure itself on if it were to

and bite, stand on, kick or knock into the handler and the researcher.		become upset and that any rugs it is wearing are securely fastened and pose no risk. The horse will be properly restrained in a safe manner whilst the bridle is put on by placing the head collar round its neck and untying the rope from the wall but leaving it through the twine so it does not hang on the floor. The researchers will ensure that they are aware of their position in relation to the horse in case the horse does become upset. The researchers will both be wearing suitable riding hats and the handler will also be wearing gloves. The riding hat must be up to standard, PAS 015/BSEN 1384 or equivalent. Further to this a special safety attachment will be used with the tension gauge so that if in this period or future work with the equipment, it should break then the rein is still connected negating possible injury risk.
Risk of the researchers or the horse falling over between the stable and walker and injuring themselves	Researchers and the horse	The researchers will be wearing sturdy boots, a hat and gloves as stated by Myerscough College safety rules. The researcher will have checked the area to be free from hazard before taking the horse to the walker and both researchers will go to and from the walker for added safety.
Risk of the horse becoming upset and/or injuring itself on the walker.	The horse	At least one researcher will be present for the entire time that the horse is on the walker with the sensors and tape locations applied. The bridle will be removed whilst the horse is on the walker to ensure it cannot become tangled or upset the horse in any way that could cause possible injury. If the horse appears to become distressed at any point or shows unexpected behaviour it will be removed from the walker immediately, taken back to the stable and the markers quickly but safely removed.
Injury to the horse during the habituation period in the stable and on the walker.	Horse and the researchers.	The habituation period in the stable and walker will be as safe as possible. The stable, walker and surrounding area will be assessed for potential risks to both horse and people. Risks assessed include: positioning of haynets and feed buckets, loose rugs, positioning of any yard tools and equipment, icy concrete, bad weather and people working in the immediate vicinity.

Injury to researchers and the horse due to ice.	The researchers and the horse	All areas must be assessed to be suitable for humans and horses to walk on before attempting to do so. Sturdy suitable footwear must be worn by researchers so not to increase the likelihood of a slip. The horse must be kept calm and at a walk when on route to the walker again to minimize occurrence of slip.
Fire	The researchers, horse, yard staff and general public	Researchers will be made aware of fire procedures before commencement of the habituation procedure. Fire escape routes, and individual roles and responsibilities in case of fire will also be discussed.

RISK ASSESSMENT TITLE **Investigation of different equestrian surfaces and their effects on the horse's movement during flat work and over jumps**	PROGRAMME AREA **Equine Surfaces Research Group**	ASSESSMENT UNDERTAKEN **Signed: Laura Dagg / Emma Blundell / Alison Northrop** **Date: 15 November 2010**	ASSESSMENT REVIEW **Date:**

STEP ONE	STEP TWO	STEP THREE
List significant hazards here:	***List groups of people who are at risk from the significant hazards you have identified.***	***List existing controls or note where the information may be found. List risks which are not adequately controlled and the action needed:***
General handling of the horse includes risks of being knocked over, stood on kicked or bitten.	The researcher, rider, and co-worker	All study researchers and participants have a history of handling horses and are experienced in being watchful of the horse in relation to themselves. Personal protective clothing will be worn at all times including a riding hat (BS EN 1384 or PAS 015), gloves and sturdy footwear. The horses will be restrained by the use of a headcollar or bridle during all of the procedures discussed here involving the horses.
Clipping the horse for EMG sensor application includes the risk of tripping or falling over wires. Also risk of electric shock.	The researcher and co-workers	All clipping must be done in a safe designated area and clippers will be wireless. No electrical equipment will be left unattended during the clipping process. Clippers electrical will be checked that they are in good working order prior to use. Clipping is routine practice and the horses used will be regularly clipped and will be familiar

		with the process. Razors will be used to complete shaving process. Care will be taken to remove the hair and razors will be stored safely in between use.
Clipping the horse also involves risk to the handler from the horse becoming upset by the clippers or clipping process. Workers could be bitten, kicked or stood upon.	The researcher and co-workers	A riding hat to current British safety standard (BS EN 1384 or PAS 015) and sturdy footwear must be worn by the person handling the horse and the person clipping at all times. The horse involved in the study must have been clipped previously and have shown relaxed behaviour. The process must be stopped immediately if the horse shows signs of significant stress, or the handlers decide it unsafe to continue with the process. This is unlikely because all horses used in the study will be used to being clipped as part of their normal management routine.
Positioning markers on the distal limb includes risk of being knocked over, stood on, kicked or bitten.	The researcher and co-workers	All researchers and co-workers participating in collecting data will have undergone Myerscough college yard induction and safety training and be experienced with handling horses. Researchers must be aware at all times of their position in relation to the horse. Personal protective clothing should be worn (sturdy boots, gloves and a riding hat to current safety standards PAS 015/BSEN 1384 or equivalent).
Positioning EMG markers onto proximal muscle areas of the horse includes risk of being kicked, knocked over, bitten or stood on.	The researcher and co-workers	All researchers and co-workers participating in collecting data will have undergone Myerscough college yard induction and safety training and be experienced with handling horses. Researchers will be aware at all times of their position in relation to the horse. Personal protective clothing should be worn (sturdy boots, gloves and a riding hat to current safety standards PAS 015/BSEN 1384 or equivalent).
Applying the accelerometer to the hoof wall includes risk of being kicked, stood on and knocked over. Further risk of back injury can apply if bent over for a long period of time to apply the equipment.	The researcher and co-workers	All researchers and co-workers participating in collecting data will have undergone Myerscough college yard induction and safety training and be experienced with handling horses. Researchers must be aware at all times of their position in relation to the horse. Personal protective clothing should be worn (sturdy boots, gloves and a riding hat to current safety standards PAS 015/BSEN 1384 or equivalent). Researchers must make sure that at no time they kneel on the floor but instead bend their knees whilst keeping a straight back. The researcher positioning the

		accelerometer will swap if the adjustment takes a long time (more than 10-15 minutes). Wires from the accelerometer will be held securely and safely in place with use of adhesive tape. A mock up accelerometer complete with mock up cables and data logger will be used for habituation purposes allowing the connective wires to easily brake if necessary. Once the horse is successfully habituated to the mock equipment it can be substituted for the real equipment and data collected progressively from walk through to trot and canter before jumping
General handling and moving of equipment includes risk of back injury as well as arm, hand, leg and foot injury if equipment is dropped.	The researcher and co-workers	Ensure correct manual handling techniques are known and used at all times when moving equipment such as jump wings and poles. If the item in question is considered too heavy it must be moved between two people to avoid injury. All researchers and co-workers will be aware of this.
Familiarisation of the horse to the equipment and testing procedure includes risk of horse knocking over, standing on or kicking someone. The rider is also at risk of falling off.	Researcher, co-workers, rider	Initial habituation will take place in the stable and during in-hand work. The horse will be handled at all times by competent staff throughout the habituation process and the pilot study. The riders participating are experienced and will warm the horse up gradually to keep the animal relaxed. The height of the fence to be jumped will be built up slowly to ensure the horse is coping well with the procedure. Care will be made that all researchers are at a safe distance of the horse at all times it is working. Heart rate will be measured throughout and if found to rise above 180bpm the horse will be warmed down and data collection will cease to avoid possible accidents.
The study includes risks of the researcher and co-workers, bumping into or sliding on equipment used.	Horse, rider, researcher and co-workers	The arena will be set up before the horse is tacked up and brought in with extra attention paid to making sure that all wires and equipment used are positioned safely. All electrical equipment shall be placed as near as possible to the side of the arena so that wires are not running across the horse's path. All wires that do reach the floor shall be safely placed under matting and covered with the arena surface.

		Wires running out of the arena shall be securely taped to the floor to avoid trips. The site will have been risk assessed before hand to make sure that the arena surface is level and in good condition and that researchers are aware of entrances and exits, fire escapes and assembly points and first aid stations. No unauthorised persons shall be allowed into or around the testing area or near the equipment. Notices will be placed in the testing area to ensure this.
Electrical equipment could become faulty and cause injury.	The researcher, co-workers, rider and horse	All equipment will have been PAT tested and checked prior to use for loose wires or possible problems. Equipment which needs to be connected to a main power supply will have a circuit breaker attached.
The habituation and trials both pose a chance of the rider falling off and becoming injured.	The rider	The rider will be wearing the correct safety equipment and clothing as stated by Myerscough College rules. During the study there will be a first aider either present or present on the equine yards at Myerscough and they will be told about the work so they will be aware. A first aid kit and a mobile phone will be available on site in case of an emergency.
The habituation and trials both pose a risk of injury occurring	The rider, researcher and co-workers	Qualified first aider and first aid kit will be on site during set up and testing. It will also be ensured that there is a mobile phone available in case the need to call the emergency services arises. A first aid box and the first aider will be located before the testing begins
The testing procedures includes the risk of slipping when inside or exiting the	The researchers, co-workers, rider	Be aware at all times of the surface being stepped on and take time to clean any excess build up of surface material of shoes whilst in and outside the arena.

arena due to the surface material underfoot.		
The dust from the arena surfaces may cause irritation to the eyes, nose and mouth	Rider, researcher and co-workers	The rider, researcher and co-worker will be warned about the possible affects the dust may have and will be asked to report any discomfort to these areas to the first aider immediately.
Risk of electrocution due to rain	Rider, researcher and co-workers	The testing will not be performed in the outdoor arena if it is raining however there is always a potential risk. The weather forecast will be continuously checked throughout the day. Circuit breakers are used on all extension cables
Zoonotic disease	Rider, researcher and co-workers	Hands washed and good hygiene will be expected by all personnel involved.
Allergy to horses	All personnel involved in the trials	All personnel involved in the trials will be aware that horses will be used in the study and the lead researcher will ensure that all members of the team are not allergic to horses. In the event of an allergic reaction occurring a first aider will be called (as above) and treatment will be suggested according to severity of reaction.

MYERSCOUGH COLLEGE

RISK ASSESSMENT TITLE	PROGRAMME AREA	ASSESSMENT UNDERTAKEN	ASSESSMENT REVIEW
Use of machinery for arena maintenance	Equine	**Signed** **L. Dagg** **Date:** **26/01/11**	**Date:**

STEP ONE	STEP TWO	STEP THREE
List significant hazards here:	**List groups of people who are at risk from the significant hazards you have identified.**	**List existing controls or note where the information may be found. List risks which are not adequately controlled and the action needed:**
Slipping, falling when climbing on to tractor.	Researcher and co-workers.	Only trained staff to use tractor. Suitable PPE must be worn when using the tractor including suitable sturdy footwear to avoid slips and trips.
The study involves the risk of driving a vehicle with attached machinery in a possibly confined space. The driver may crash and become injured or strike a	Researcher, co-workers and members of the public.	Only trained staff to use tractor at all times. Drivers must be taught the correct techniques for handling the machines at speeds, with implements, braking, and parking before commencement of testing. All other researchers must be aware of their position in relation to the vehicle at all times and exit the area when the

researcher or member of the public.		vehicle is being driven from one location to the next. The driver must ensure the area is clear and safe before attempting to move the vehicle. Members of the public must be kept away from the testing area and informed by researchers of areas which are unsuitable to enter. Suitable PPE must be worn when using the tractor including suitable sturdy footwear to avoid slips and trips
The study involves the risk of reversing a vehicle with attached machinery. The driver may crash or strike a researcher or member of the public.	Researcher, co-workers and members of the public.	Only trained staff to use tractor at all times. The area must be fully checked to make sure that there is no risk of injury to any other person or to the equipment in use. Only move if it is safe to do so. All other researchers must be aware of their position in relation to the vehicle at all times and exit the area when the vehicle is being driven from one location to the next.
The study involves the risk of injury to researchers when hitching up appliances to the tractor.	Researcher and co-workers.	Ensure correct manual handling techniques are known and used at all times when moving equipment. If the appliance in question is considered too heavy it must be moved between two people to avoid injury. All researchers and co-workers will be aware of this. Suitable PPE must be worn when using the tractor including suitable sturdy footwear.
The study involves the risk of damaging machinery, colliding with an obstacle or person and scaring horses when driving to the arenas.	Researchers, co-workers, members of the public and horses.	Only trained staff to use tractor at all times. The area must be checked to be free from blockage and hazards before attempting to travel to the arena. The driver must be aware of the public walking in these areas and also of horse that may need to be led pass. In the event of horses needing to pass the tractor will be turned off to allow safe passing and turned back on once the animals in question are suitably clear.
The study involves harrowing, rolling, and grading arenas with use of heavy machinery.	Researcher and co-workers.	Only trained staff to use tractor at all times. The area must be fully checked for hazards prior to starting to make sure that there is no risk of injury to any other person or to the equipment used. Only move if it is safe to do so. All attached appliances must be fitted correctly before movement of the tractor and

		equipment must be deemed safe and suitable for use. Researchers must be aware of the arena dimensions, kick boards and fencing so that the machinery does not cause damage to the school. Suitable PPE must be worn when using the tractor including suitable sturdy footwear.
Zoonotic disease through using shared agriculture machinery and being in close proximity to animals.	Researcher and co-workers.	Hands washed and good hygiene will be expected by all personnel involved.

MYERSCOUGH COLLEGE

RISK ASSESSMENT TITLE Riding on the test track. Staff and students.	PROGRAMME AREA Equine	ASSESSMENT UNDERTAKEN Signed: K. Owen/ L. Dagg Date: March 2011	ASSESSMENT REVIEW Date: March 2012

STEP ONE	STEP TWO	STEP THREE
List significant hazards here:	**List groups of people who are at risk from the significant hazards you have identified.**	**List existing controls or note where the information may be found. List risks which are not adequately controlled and the action needed:**
Falling off	Students, staff and invitees	Rules of the school and riding Safety Policy are clearly understood by riders. See induction document for correct riding equipment. Students are only allowed to ride onto the test track surface if a member of staff is present and has allowed them to do so after checking for possible hazards.
Horse colliding with perimeter fence	Students, staff and invitees	Riders must only take horses onto the test track if it is deemed suitable to do so by a member of staff. The horse must be calm and fully under control before

		any attempt is made to ride onto the track and riders must be aware of their positioning at all times.
Being Kicked by another Horse whilst Riding	Students, staff and invitees	Students are to stay in single file when riding onto and off the test track and be aware of other riders position in relation to their own at all times.
Rearing/spooking/shying/bolting horse	Students, staff and invitees	All riders to be aware of their position in relation to others at all times. All riders listen to the member of staff in charge of the group at all times and in an unexpected situation do asked. Riders should come to a halt until all horse are under control.
Loose Girth, incorrectly fastened tack.	Students, staff and invitees	See induction document for correct taking up. All riders must make sure that girths are tightened and that all tack in properly adjusted before riding from the arena onto the test track surface.
Visiting horse may be more spooky and unsettled in a strange environment.	Students, staff and invitees	Make sure all Invitees are aware of the Myerscough riding policy and are wearing the correct equipment as stated in the induction document. Riders must only take horses onto the test track if it is deemed suitable to do so by a member of staff. The horse must be calm and fully under control before any attempt is made to ride onto the track and riders must be aware of their positioning in respect to researchers and other horses at all times. Ensure the horse is given enough time to settle into the environment.

Appendix C – Study Registration

UNIVERSITY OF CENTRAL LANCASHIRE

FACULTY OF

FACULTY RESEARCH DEGREES SUB-COMMITTEE

Application to Register for a Research Degree

Section One (Academic Issues)

1. **The Degree**

Submitted by (*Centre for applied sport and exercise sciences)*

for the degree of MSc by Research

(delete as appropriate)

2. **Project Title**

The effect of two different surface maintenance procedures on motion of the equine hoof and metacarpophalangeal joint.

…………………………………………………………………………………………

3. **The Applicant**

Full Name: Laura-Anne Dagg Sex: Female

E-mail address: ldagg@myerscough.ac.uk Date of Birth: 08/11/1983

4. **Period of Time for Completion of Programme of Work**

4.1 Starting date for registration purposes:	Jan/11
4.2 Mode of study (full-time or part-time):	Full
4.3 For students based off - campus details of expected attendance and frequency of contact with University and supervisors (non UK resident must be part-time only)	N/A

5. **The Programme of Research:**

The primary aim of the research is to compare the amount of movement in the hoof and the metacarpophalangeal joint (MCPJ) of the horse during flat and jump work on two different preparations of a single arena surface. The movement of the hoof as well as the angle of flexion and extension of the MCPJ will be measured in the front legs of the horse first working over ground poles in walk, trot and canter and finally during the landing of a jump. To determine the amount of movement seen in the hoof and the MCPJ, reflective markers will be used alongside a set up of 10 three dimensional (3D) motion analysis cameras.

The secondary aim of the research is to investigate whether there is a relationship between the movements seen and the mechanical properties of a surface after general maintenance procedures. An arena surface comprising of waxed sand and felt mix (Andrews Bowen Pro Wax) will be prepared in two different ways using standard arena maintenance equipment e.g. roller and harrower. Surface hardness, penetration resistance and traction will be measured for each preparation using mechanical apparatus that has been validated in previous studies. The horses will then be worked on the surface as outlined in the primary aim and findings then compared.

Extension of the MCPJ has been described as being a passive event caused by the vertical forces placed up on it (Johnston and Back, 2006). During the stance phase of the stride the hooves of the front limbs are planted firmly down on to the surface causing a large increase in horizontal breaking force as well as vertical forces which are transmitted up through the limb (Johnston and Back, 2006). Extension of the joint is at this point resisted by the superficial digital flexor tendon (SDFT), deep digital flexor tendon (DDFT) and the suspensory ligament (SL) (Clayton, 1999; McGuigan and Wilson, 2003; Smith *et al.,* 2002). The supporting structures, along with the bones, are therefore subjected to high peak forces, concussions and strains meaning that failure and consequently injury is often seen (McGuigan and Wilson, 2003; Smith *et al.,*2004). A single catastrophic event can cause breakdown of the horse during locomotion, it is however more often that injuries are caused by repeated trauma sustained during training and competition (Clayton, 1997). Age related changes such as osteoarthritis of the joint cartilage has been found to increase in severity of biomechanical loading (Radin *et al.,* 1983). In addition, loading rates may affect degeneration in the bones and supporting structures, which vary with loading intensity and factors such as ground surface substrate (Clayton, 1997; Smith *et al.,* 2002). Limb impact and hoof deceleration are therefore directly influenced by the surface-hoof interaction (Crevier-Denoix *et al.,* 2009; Johnston and back, 2006). Initially the heel is seen to sink during the impact phase which is then followed by forward toe rotation from midstance through to break over when working on compliant surfaces (Johnston and Back). Slippage or even rotation of the foot on the surface during the stance phase of the gait can therefore affect the natural locomotion and the loading on the limb. Movement such as this during impact is reported to be a common cause of injury to the supporting structures of distal limb joints (Clanton *et al.,* 1991). The surface substrate as well as the preparation it receives are therefore attributed to having a major effect on the coefficient of friction (Gustas *et al.,* 2006). Further to this normal levels of axial rotation and collateromotion seen in the distal interphalangeal joints are increased by asymmetric placement of the foot on uneven surfaces (Chateau *et al.,* 2001). The relationship between the distal limb and the surface is therefore now a growing area of interest and is certainly considered to an important factor in the occurrence of injury (Weishaupt, 2010).

Artificial surfaces are commonly used for training and competing horse of all levels (Murray, *et al.,* 2010). There are currently however no set standards or regulations governing the type of surfaces available or the maintenance procedures necessary to maintain optimum health and wellbeing of the horses working over them (Weishaupt, 2010; Wheeler, 2006). Surface substrate and treatment can affect the limb loading rates, shock attenuation, supporting structure loads and accelerations and decelerations of the limb and hoof (Gustas *et al.,* 2006; Hobbs *et al.,* 2010). Recent work regarding horse and ground interaction has often focused on racehorses and therefore race tracks (Burn and Usmar, 2005; Dallap-Schaer *et al.,* 2006; Peterson and McIlwraith, 2008; Ratzlaff *et al.,* 2005) but as Murray *et al* (2010) reports there is less available knowledge regarding other equestrian disciplines and surfaces. The optimum surface to work a horse on for any given discipline is yet to be agreed but is described by Barrey *et al.* (1991) as needing to be able to minimise concussion through energy absorption whilst still returning suitable power to aid performance. An overly hard surface causes rapid deceleration of the hoof at impact resulting in maximum concussion in the tissues and damage to the articular cartilage and supporting structures (Barrey *et al.,* 1991; Ratzlaff *et al.,* 1997). An overly soft surface however can cause muscle fatigue which in turn leads to damage of the flexor tendons as the horse tries to push itself out of the surface and off the ground (Murray *et al.,* 2010). Weishaupt (2010) states the need for objective information and new ways to investigate and then evaluate limb-surface interactions are much needed. The effect on maintenance procedures on existing surface properties is therefore of much interest.

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Appendix D – Rider Consent Form

Participant Information Sheet – Rider

You have been invited to participate in a piece of equine research at Myerscough College. The research will involve measuring limb inclination, fetlock angle, acceleration and muscle activity on the flat and over jumps (up to 1m high). This form provides basic information regarding the testing as well as asking for your consent to participate in the study. If you have any questions which you feel are unanswered by the information provided below then please do not hesitate to contact the research team on the details provided at the end of this form.

The testing procedure

Before any work commences you will be required to complete the PAR-Q questionnaire provided. The questionnaire allows the team to be sure that you currently have no medical problems that would preclude you from participating.
Study work will take place on the arenas at Myerscough College and will involve some indoor and outdoor work (weather dependent). You will be asked to ride one horse, testing will involve a warm up of around 15 minutes to include work on both reins in walk, trot and canter. Once warmed up the equipment will be activated and you will be asked to continue riding on the flat whilst the team collects data. At this early stage of the work some of the equipment may need adjusting and resetting throughout the test period. The research team will make sure that at no point is the horse stood for any length of time whilst equipment is altered. Some jump work will either commence further to this on the same date or on a later date. Jump work will commence as follow. After a suitable warm up the horse will be worked over a pole on the ground, which will then be gradually built to 1m in height. The jump will then be built into a spread and jumped at least once. You will then be asked to warm the horse down. In the unlikely event that the horse is used for up to 2 hours in any one testing session, a break will be enforced for 1 ½ hours before commencement of the work.

Risks

A full and thorough risk assessment has been carried out by the Myerscough research team to minimise any potential risks to yourself, the horses and the researchers. The main risk of taking part would be falling off the horse and injuring yourself. You have been invited to take part in this study as you are a competent horse rider who rides on a regular basis and has done plenty of jump work previously. The horse used will have been habituated to the equipment before the testing date to reduce risk of stress and possible injury to yourself or the horse. You will not be asked to do anything that you would not experience during an affiliated show jumping round.

Consent

Participation in the study is voluntary and you are able to withdraw at any time during any part of the testing. Once the testing is complete consent cannot be withdrawn so it is important to make sure you have read this information and asked any questions before completion of testing.

Collected data

All data that is collected from your participation will be anonymous and results will be analysed and used to determine future research work. The information you provided before the testing in the PAR-Q and signature to agree to test is to ensure your safety and eligibility. Information you have provided will be safely and securely stored in a locked filling cabinet.

Ethical Consent

Ethical consent for the study *has been applied for to the Myerscough College committee and the University of Central Lancashire.

*N.B. This will be modified to 'has been approved by' when approval is granted

If you are happy to go ahead with participating in the testing please sign the attached consent form. It is a requirement you provide a signature to reflect agreement to perform the research.

All communications should be made to,

Dr Sarah Jane Hobbs,

Senior Lecturer in Sport and Exercise,

Centre for Applied Sport and Exercise Sciences,

University of Central Lancashire,

Preston,

PR1 2HE

Tel: 01772 893328

Email:SJHobbs1@uclan.ac.uk

Agreement to testing

I understand the risks associated with this study and that all the data produced will be treated with confidentiality and individually. If I wish, the results produced will be available to me.

I willingly agree to participate in the current study. I have read the above information and understand that withdrawal from the study is possible until all data has been collected.

Name of participant;

Print Name: ……………………………………………………………………

Signature: ……………………………………………………………………….

Date: …….. /…….. /………….

Witness

Print Name: ……………………………………………………………………

Signature: ……………………………………………………………………….

Date: …….. /…….. /………….

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ________________________________

SIGNATURE ________________________ DATE ________________________

SIGNATURE OF PARENT ________________________ WITNESS ________________________
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

CSEP | SCPE

Appendix E – Manufacturers Surface Recommendations

Manufacturers' Surface Maintenance Recommendations

Company	Substrate offered	Variations			Suggested base	Suggested Maintenance	Suggested Equipment	Water
Ascot	Silica Sand	Same version but waxed sand	Fibre mix		Stone	Subject to traffic, minimum once per week	Harrow & grader	When needed but not for wax
Combi-ride	90% industrial silica, pulverised nylon, rubber crumb	Same version but waxed sand				Every day 20 minutes	Arena mate grader	Only water if a 5-6 weeks spell of no rain
Equestrian surfaces	Cushion track' wax silica sand, nylon, rayn, polyester	No rubber, environmental reasons for europe	Dry mix with no wax	Sand alone, also fibres available to buy to mix	Mini requirement for them to build on is top quality hard stone	Subject to traffic, cheaper surface more maintenance. Every 12 months get it levelled.		No watering needed for wax, others should be fine if maintained. Only water if really dried out.
Leisure Ride	Sand based silica, blend of synthetic hair	Different fibres used for the type of footing wanted. Dressage firm footing, Inch of cushioning. SJ			40mm clean stone, only use granite, dust	Anything with fibre use a spring tine harrow to comb surface rather than drag. Want to take out footprints		Non-waxed needs watering during dry

	fibres, polyesters. Offer hot wax, non wax and cold wax.	Softer more cushioning. Racing want a deep loose footing, works them heavily.		free, screened.	opposed to dig it. Then roll it after. Once a week at least. Six weeks pull edges down.		periods to keep surface together. Hot Wax not needed. Cold wax if weathers very dry.
Soft track	Soft track mix sand, elastic fibre, geo fibre, hot wax.	Also fibre mix which is unwaxed, manufactured sand mixed with fibres.		Hard stone	Harrowing		Soft track no watering, fibre mix only if really dry.
Williams and Williams	Sand alone. Sand and rubber mix	Or premixes. Standard Pre mix top grade silica sand, rubber and rayon fibres. Pro surface if school gets a lot of usage silica rubber granules, short and long rayon fibres and polyesters. Non waxed.	Felt you can add to a school riding deep	Clean lime stone base but is regional	Must have droppings removed daily for dust. Once a week grading.	Harrower or grader. Mayfield engineering	Indoor needs watering once a week. Hot spell outdoors might need a water but other than none. Sold as all weather.
Martin Collins	Wax coated surface. Activtract has sand, fibre and pvc	Eco track is sand, fibre and rubber. Wax coated also		Recommended spec non frost permeable stone with two membranes	At least once a week but heavy use increase it.	Harrow and grader. Equally as important as surface	Wax coated no watering. Unwaxed kept moist for best performance.

Equestrian direct	Olympic standard. Non wax high grade silica sand and mixed with binding fibre	Discipline and usage. High use complete flexi ride. Synthetic alt to rubber goes onto the base with no sand.		Lime stone base but again regional.	Indoor a few times a week. More during competition. Harrow and roller.	Usage. Equi level. It is a leveller and roller in one and waters	No watering for light use if arenas outdoors.
Witham Vale	No exclusive surface for the company. Sand and rubber or sand and fibre mix.	Waxed and non-waxed available		Regional	Once or twice a week	With a leveller	May water but only in prolonged dry spell.
John Homyak	Pure synthetic polypropylene fibre. New not second hand bits of carpet. Non mixed. Used alone.			Well drained agrigate surface.	Maintenance is very low. Does not freeze.	Needs no machines, rolling or harrowing	Indoors a bit of sand underneath and minimal water to keep moist. It is built for outdoor however.

Appendix F – Standard Operating Procedures for the Clegg Impact Tester and Torque Wrench

EQUINE RESEARCH GROUP STANDARD OPERATING PROCEDURES

ERG-SOP 21. DETERMINATION OF HARDNESS

[1] Scope

This standard operating procedure specifies a method of testing to determine hardness of turf and synthetic surfaces.

[2] Principle

A cylindrical mass is released from a standard height and its peak deceleration during impact with the turf surface is recorded.

[3] Apparatus

A Clegg Impact Soil Tester shall be used. The apparatus consists of a cylindrical compaction hammer with a mass of 2.25 kg and a diameter of 50 mm attached to a piezoelectric accelerometer which feeds into a peak level digital meter. The peak deceleration of the hammer on impact with the ground is displayed in gravities on the liquid crystal display of the digital meter.

[4] Procedure

Ensure that the guide tube is held vertically and drop the compaction hammer down the tube from a height of 450 ± 10 mm (as identified by the white line marked on the weight). After the impact of the hammer on the turf surface, the peak deceleration displayed by the digital meter shall be recorded in units of gravities. After each test the guide tube shall be moved so that the compaction hammer does not impact with the surface on the same spot twice.

[5] Number & Distribution of Readings

Replicate measurements will need to be made. The number and sampling interval should be decided following initial pilot testing on a similar surface.

[6] Expression of Results

Calculate the mean hardness value for each area in gravities.

The 2.25 kg Clegg hammer

ERG-SOP 22. DETERMINATION OF TRACTION

[1] Scope

This standard operating procedure specifies a test for the determination of traction of turf and synthetic surfaces.

[2] Principle

Measurement is made of the force required to initiate rotational movement of an appropriate selected disc which is in contact with the surface.

[3] Apparatus

The apparatus which shall be used consists of the following components:

[a] a mild steel disc 145 ± 1 mm in diameter and 12 ± 2 mm thick, centre drilled. Disc selection will depend on the surface being tested.

[b] an 800 ± 25 mm long shaft with attached lifting handles which threads into the centre of the studded disc.

[c] a set of annular weights which rest centrally on a bearing on the upper surface of the studded disc allowing free movement of the disc beneath the weights. The weight used should be determined following appropriate pilot testing of a similar surface.

[d] a standard torque wrench with a scale up to 80 N m which attaches to the top of the steel shaft.

[4] Procedure

Assemble the apparatus. Set the torque wrench indicator needle to zero, then drop the apparatus from a height of 100 ± 10 mm onto the surface. This ensures that the selected disc embeds into the surface. Without placing any vertical pressure on the torque wrench but keeping the central pivot point stable, turn the apparatus until the surface yields and no further increase in torque occurs (NB the movement should be steady but firm, and travel at least 90°). Record the value displayed on the torque wrench to the nearest N m. Before conducting the next test the apparatus must be moved to an area of fresh surface and the disc cleared of any debris.

[5] Number & Distribution of Readings

Replicate measurements will need to be made. The number and sampling interval should be decided following initial pilot testing on a similar surface.

[6] Expression of Results

Calculate the mean traction value for each area in N m.

The components of the traction apparatus