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Research Paper

Comparison of equipment used to measure shear properties in equine arena surfaces

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The design of a novel apparatus, the Glen Withy torque tester (GWTT), for measuring horizontal shear properties in equine sport surfaces is described. Previous research has considered the effect of vertical loading on equine performance and injury but only limited discussion has concerned the grip or horizontal motion of the hoof. The horizontal support of the hoof by the surface must be sufficient to avoid excess slip without overloading the limb. The GWTT measures the torque necessary to twist an artificial hoof that is being pushed into the surface under a consistently applied vertical load. Its output was validated using a steel surface, then was used to test two sand and fibre surfaces (waxed and non-waxed) through rotations of 40–140°, and vertical loads of 157–1138 N. An Orono biomechanical surface tester (OBST) measured longitudinal shear and vertical force, whilst a traction tester measured rotational shear after being dropped onto the surfaces. A weak, but significant, linear relationship was found between rotational shear measured using the GWTT and longitudinal shear quantified using the OBST. However, only the GWTT was able to detect significant differences in shear resistance between the surfaces. Future work should continue to investigate the strain rate and non-linear load response of surfaces used in equestrian sports. Measurements should be closely tied to horse biomechanics and should include information on the maintenance condition and surface composition. Both the GWTT and the OBST are necessary to adequately characterise all the important functional properties of equine sport surfaces.

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Nomenclature

DDFT	deep digital flexor tendon
D_{max}	peak vertical displacement (GWTT) (mm)
GWTT	Glen Withy torque tester
$GRFH_{max}$	peak longitudinal ground reaction force (OBST) (kN)
$GRFV_{mean}$	mean vertical ground reaction force (GWTT) (N)
$GRFV_{max}$	peak vertical ground reaction force (OBST) (kN)
OBST	Orono biomechanical surface tester
SDFT	superficial digital flexor tendon
SL	suspensory ligament
Slip	horizontal displacement from impact to $GRFV_{max}$ (OBST) calculated from double integration of *GRFH* (mm)
T_{max}	peak torque (GWTT) (Nm)
T_{maxTT}	maximum recorded torque (traction tester) (Nm)

1. Introduction

The loading of surfaces by horse hooves is complex due to both the range of gaits and speeds and the manoeuvres performed by the horse and the diverse characteristics of the different surfaces. The functional properties of racetrack surfaces have been studied extensively (Peterson, Roepstorff, Thomason, Mahaffey, & McIlwraith, 2012; Ratzlaff, Hyde, Hutton, Rathgeber, & Balch, 1997; Reiser, Peterson, McIlwraith, & Woodward, 2000; Setterbo, Fyhrie, Hubbard, Upadhyaya, & Stover, 2012) but less is known about the characteristics of arena surfaces that are often used for non-racing equestrian sports which involve a more diverse range of athletic activities and hoof surface interaction patterns. In nearly all cases surfaces used for equestrian sports are both highly non-linear and strain rate dependant. For instance, the surface response when executing a canter pirouette in a dressage competition may be quite different to a quick turn during the jump off of a show jumping competition. As the load on the surface increases the typical riding surface increases in stiffness (Reiser et al., 2000) and, in general, the surface will also become stiffer as the load is applied at a higher rate (Setterbo et al., 2012). Since shear resistance of a surface is directly related to the surface stiffness, the grip characteristics are also expected to change with load and loading rate. Thus, there is a need to understand the responses of arena surfaces to both the speed and magnitude of loading, as the stiffness and shear resistance of the surface will influence both the horse's ability to perform and the risk of it receiving an injury.

Shear resistance relates to the frictional forces that are generated between the hoof and the surface and to friction between the particles within the surface (Hobbs et al., 2014). Linear shear resistance affects sliding of the hoof across the surface in a horizontal plane especially during braking phase of stance in straight-line movement. It also affects resistance of the surface when the hoof is in an angled position relative to the ground, as found during push off and sharp turns. Rotational shear resistance affects rotation of the hoof into the surface material, which is also seen during push off and sharp turns. The sliding of the hoof on the surface can either occur between the shoe and the surface, or within the material beneath the hoof depending on the specific characteristics of the surface and the design of the shoe. In addition, the forces generated by the horse's musculotendinous system tend to rotate the hoof into a toe-down orientation within the surface material as the limb generates propulsion (Thomason & Peterson, 2008). The surface must provide sufficient resistance to the horizontal sliding motion or rotation of the hoof to enable the horse to obtain grip, which prevents slipping, tripping or falling (Murray, Walters, Snart, Dyson, & Parkin, 2010a) and provides traction for propulsive effort (Crevier-Denoix et al., 2010). Excessive resistance to the horizontal motion or rotation is expected to result in an earlier onset of hoof braking and an increase in the magnitude of the peak stress and loading rate in the limb (Gustås, Johnston, & Drevemo, 2006). Reduced horizontal motion of the hoof has been associated with surface hardness (Orlande, Hobbs, Martin, Owen, & Northrop, 2012; Wilson & Pardoe, 2001) and harder surfaces tend to increase the magnitude of higher frequency vibrations during impact and limb loading (Chateau et al., 2009). The high frequency components of the loading are reported to be attenuated mainly by the hoof, and the magnitude of peak stress is gradually damped proximally by the distal limb structures (Lanovaz, Clayton, & Watson, 1998; Willemen, Jacobs, & Schamhardt, 1999). High frequency loading damages bone and articular cartilage predisposing to the development of osteoarthritis (Folman, Wosk, Voloshin, & Liberty, 1986). Insufficient friction and shear resistance can lead to excessive slip and shearing of the top layers of the surface during braking, limiting the traction available for propulsion. Excessive slip during braking causes the horse to reduce stride length as a means of reducing the longitudinal braking force (Chateau et al., 2010) which adversely affects performance. It may also result in rider falls and accidents (Crevier-Denoix et al., 2010; Murray et al., 2010a). Insufficient friction and shear resistance can lead to shearing of the top layers of the surface and result in increased rotation of the hoof into the surface. Excessive slip will then occur during braking, and traction will be lost for propulsion, which is known to increase fetlock joint extension (Crevier-Denoix et al., 2010). Conversely, during midstance maximal fetlock joint extension is reduced which is likely to reduce the storage and release of passive strain energy in the superficial digital flexor tendon (SDFT) and the suspensory ligament (SL) (Crevier-Denoix et al., 2010). The deficit in passive strain energy is proposed to be compensated by a greater active contribution of the deep digital flexor (DDF) muscles to maintain speed (Crevier-Denoix et al., 2010). Early onset of fatigue in the DDF muscle results in greater passive strain of the SDFT which is then at risk of overloading and injury (Butcher et al., 2007). High quality artificial and natural surfaces are needed for equestrian sports in order to provide an appropriate balance between injury reduction and optimal performance of the equine athlete. Shear resistance of the surface is a complex and important factor in this equation and one that has not been adequately evaluated, in part due

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