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## Artificial Turf Research at Loughborough University

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### Abstract

Research into artificial turf surfaces can be divided into the categories infrastructure, user safety and play performance. This paper discusses these three categories, presents current knowledge and appraises some remaining questions. A simple diagrammatic framework is proposed for describing and relating the fundamental components of sport surface related research. Infrastructure includes the design, construction, operation, and whole life costs associated with a facility. A key area for future research is to better understand maintenance and the benefits of various strategies / techniques. User safety, or injury risk, is a key concern for many stakeholders. Injury risk is a complex interaction of many factors related to the user, sport, equipment and environment. Whilst the introduction of an injury consensus in the late 1990s permitted much greater impact of studies in soccer and rugby, these have contributed little to understanding injury mechanisms. Furthermore, previous research is hampered with regard to the effect of the surface by utilizing simple mechanical tests that appear inappropriate to user activity, e.g. traction. Advancement of knowledge within this category demands better integration with play performance related measurements and research methods that support a more mechanistic approach. Play performance has been the focus of much recent research. For example, mechanical evaluation of surface systems in the laboratory / field, player testing with regard to player and surface response and perception of surface performance. There exists a real need to develop a 'consensus' in establishing suitable boundary conditions for both mechanical and player testing. This would help to identify the fundamental research questions related to play performance and allow improved comparison between research studies.

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### 1. Introduction

Academic research into the performance and safety of sport surfaces and related areas of enquiry (e.g. climate change, carbon footprint) has in general seen an increase in the last ten or so years. This increase is perhaps linked

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to the proliferation of artificial turf surfaces in Europe through high participation sports such as soccer, rugby union and rugby league and the introduction of these surfaces into their laws of the game globally.

Sport surfaces research can be divided into the categories of infrastructure, user safety and play performance. These three (overlapping) categories can be sub-divided further; however, coalescing the current 'map' of surface related research activity and gaps in knowledge into a communicable framework is a challenging problem. This paper aims to discuss and to raise debate around these three categories. From this, a simple framework is proposed for describing and relating the components of sport surface research with the purpose of helping to unify future research in this area. This paper explores these three categories drawing upon research work carried out at Loughborough University.

## **2. Research Themes**

### *2.1. Pitch Infrastructure*

Pitch infrastructure comprises all aspects of the baseworks, including earthworks and drainage to provide a level and drainable baseworks to support the sport surface system, i.e. the shockpad and carpet. Sport pitch base design is perhaps relatively routine, but there are research issues within the industry: effective selection of the required base thickness; drainage water quality; drainage outfall water volume control; recently updated codes of practice for pitch base design and structural performance related field compliance testing using technologies from the highways industry (a current mandate of the UK's British Standards Committee PRI 57);

Current pitch design permits through-drainage of rainfall but is treated in planning as impervious. Loughborough University (LU) industry-supported research has shown that rainfall is held up in the system layers: in the surface infill, in the porous asphalt/sub base aggregate and in the pipe network, Simpson et al. (2013). These combine to act as a natural attenuation and storage system, with exfiltration into the subgrade beneath (if permeable). From the monitoring of many sites approximately 10-15% of the total volume of rainfall water has been recorded as discharged supporting new design guidance for practitioners (early 2014).

Effective maintenance of outdoor artificial turf fields is keenly debated regarding optimal maintenance strategies and efficacy of specific techniques to maximize surface durability and play performance/safety. Whilst there is much anecdotal evidence little objective testing data exists relating intensity of use and maintenance practice to pitch durability and performance. New materials and surface system designs add to the need for appropriate evidence based knowledge, in the authors' opinion. An LU industry-supported Engineering Doctorate is contributing longitudinal studies, monitoring spatial and temporal variations to evaluate system degradation and durability as well as the effectiveness of both routine and specific (for example de-compaction) maintenance interventions, McLaren et al. (2012). In conclusion, there is increasing attention on quality assurance for build and aftercare than in previous years, in addition to the sport surface quality procedures in place.

### *2.2. User safety/injury risk & performance (user focused)*

From the player perspective, the ultimate aim for any playing surface is to maximize performance and comfort whilst minimizing injury risk. All three variables can be considered important for sport played on artificial turf pitches and it is likely that an "optimal" surface will require a compromise between the three. Whilst performance is perhaps the most tangible, user safety (or injury risk) is where most previous work has focused and is arguably seen as the most important.

The most common method for investigating injuries on artificial turf has been epidemiology studies; a statistical approach where structured data collection on injuries over a substantial period of time allows inferences to be made about the incidence of specific injuries. Although this approach has yielded useful data for sports such as soccer and rugby, particularly since the introduction of an injury consensus in the late 1990s, it has a number of limitations including: time-consuming and expensive data collections; many (confounding) factors affect injury incidence in addition to the surface; challenges in adopting a consistent method of data collection and reporting to enable comparisons between studies; and a lack of insight into injury mechanisms.

Alternatively, a number of studies have used an experimental biomechanics approach to estimate loading within the human body under sub-injurious conditions and use this data to infer injury risk. Although this method can provide some insight into injury mechanisms since the player technique is quantified, the main limitation is that ethically it is not possible to design experiments with the intention of injuring participants. Hence it is necessary to rely on inferences related to injury risk and loading magnitudes, the validity of which is currently unclear.

The final approach has been through computer simulation modeling of human movement. In general, this is an area that has seen much growth over the last 10–20 years. Although there remain a number of fundamental challenges due to the complexity and redundancy within the human body, techniques have advanced to the stage where modeling is used, for example, to support clinical procedures. The key advantages of computer simulation models include: simulations can be run beyond the limits of human performance thereby allowing specific injurious scenarios to be examined; once a valid model has been established a range of scenarios can be investigated in a more time and cost effective manner; and the mechanisms of injury can be investigated. To-date few have applied this method to investigate injuries related to sports surfaces; however, it has the potential to yield the greatest insight either stand-alone or in combination with the earlier methods as a means of cross-validation.

The mechanical tests that form the basis for International Governing Body standards for artificial turf aim to ensure that a surface is safe and appropriate for the given sport. This aim could be argued as somewhat ambitious given the current lack of knowledge relating the effect of surface state on player biomechanics as well as the further projection to injury risk. It appears to rely heavily on experience and ensuring the artificial turf surfaces behave similarly to natural grass rather than from any fundamental understanding of how surface state may affect player biomechanics. To further improve artificial turf for a given sport or range of sports requires an enhanced understanding of how a specific surface state affects the player–surface interaction.

The LU framework for sport surfaces research recognizes the need to divide the player–surface interaction into two tiers. The first is to understand the effect of surface state on player biomechanics; this has included careful manipulation and characterization of surface properties and the development of novel methods to synchronously capture biomechanics and surface response, El Kati (2013; Wang, (2013). The second is to better understand the link between player biomechanics and injury risk. Although there is much on-going research in this area worldwide, few consider both player and surface as is ultimately needed to increase understanding of surface design from a safety perspective. The importance of developing a modeling strand to this work, for the reasons given above, is a key part of the future vision for this area.

Sitting alongside the strategy for developing a more complete understanding of both the player and surface, is the need for improved mechanical test methods within the standards, i.e. methods that have been shown to describe the surface state relevant to the player experience. In this regard, a further area of on-going research is the development of a database of relevant information related to player–surface interactions. The focus is on identifying the most important movements for a given sport (high frequency, high injury severity and / or high injury likelihood) and capturing player–surface data with a focus on surface loading characteristics, boot–surface contact area and boot ground contact kinematics. Although relatively simple, there remains a paucity of information on the relevant boundary conditions to use for advancing current mechanical test methods.

### *2.3. Play Performance Related Tests*

The current suite of performance related tests carried out on sport surface systems in the laboratory and field are in general simplistic and limited in their ability to replicate real human loading and in-game behaviour. However, they have stood the test of time and perpetuate within sport governing body specifications and standards. It appears there is a place for these tests in ranking pitch products and assessing relative behaviour, e.g. hardness and grip (traction). LU research in field hockey concluded on some useful correlations between player perception feedback and the data from mechanical testing, Young (2006). The issue becomes more challenging, however, when one considers how to understand the surface response and its influence on player safety or performance ability.

Three key questions arise regarding the current test methods and their place within research studies. What properties of the surface are the current mechanical tests measuring and what factors influence the results? How does subject movement and loading on a surface compare to the boundary conditions controlling the mechanical

test loading regimes? In addition, to provide comparison between surface testing studies, and field testing in particular, a third key question is: How can a surface be classified and its state described such that comparison can be made between laboratory and field data sets?

Considering shoe-surface rotational traction of a football/rugby artificial turf surface as a key player-surface performance criterion example, the three questions are considered below in light of current LU research.

Rotational traction is currently measured as the peak resistance to manual rotation of a 6-studded smooth plate under constant self-mass of 46 kg. The test stipulates that the 6-studded plate is raised and dropped by the operator manually from 60 mm to ensure good stud penetration. The six 13mm long nylon football studs are set in an equidistant formation (i.e. 60°) 4.5 cm from the center of rotation of the 120mm diameter plate. The operator uses a calibrated mechanical torque wrench to record the peak resistance which typically occurs at around 40° of rotation (Webb, 2014). The peak traction resistance is required to fall between limits as specified by the sport governing body, typically 25-50 Nm. There is currently little understanding as to the mechanism of what this test actually measures. In principle, it is clearly some form of resistance to the stud(s) shearing through the particulate material in their path – sometimes referred to as a ‘trenching’ effect.

Research has shown that for artificial turf there is little effect of either water content or temperature on peak torque; however, it is very sensitive to the normal load (test static mass) with a close to linear relationship, Severn (2010). Stud geometry and configuration has been shown to affect the peak traction with longer studs, in general, increasing traction (often normalized to cross sectional area to better account for the zone of infill in contact). It has often been assumed that full stud penetration occurs in testing. Although, where this has been measured it has raised interesting questions regarding compression of the infill and, under high normal loads, the possible effects of the sand infill and carpet base on the measured peak traction, Severn (2010). Increasing the in situ density of the infill through mechanical conditioning has also been shown to result in higher peak traction, Severn (2010).

With regard to subject movement, a recent LU study, El Kati (2013) found that during a 180° stop and turn, the average soccer boot rotation during ground contact was only 12°. The average peak initial contact vertical force was in the range of 2 bw (150 kg). The average maximum horizontal force was around 0.3 bw (23 kg) with an initial peak of 0.5 bw (38 kg). Total contact time was around 0.5 s while the initial contact peak force occurred after around 50 ms. Contact area was not directly evaluated but in a related study, Wang (2013), was estimated at 70 cm<sup>2</sup> for full shoe-surface contact of a size 10 boot, which roughly equates to a circle of 9 cm diameter. An estimate of the traction actually utilized by the player during the movement suggested that the peak coefficient (ratio of horizontal to vertical forces) occurred during the initial weight acceptance phase. Comparing the player loading data to the mechanical test it is clear that the player, in this case, exerted a much higher peak vertical load during mobilization of the traction required (to brake and change direction). The 12° average foot rotation during contact evidenced the player strategy to generate enough traction whilst limiting ankle and knee rotation and loading. The mechanical test data suggests 12° rotation is a long way short of generating peak resistance at 40° (albeit at a different normal load). Furthermore the mechanical test method stipulates a (manual) rotation speed of 12 rpm, such that if peak resistance occurs at 40° then it takes around half a second to develop. The player rate of rotation was, in this case, around four times slower than the mechanical test, though perhaps the initial player peak loading at 50 ms may be more relevant to consider regarding the material response. It is interesting to note that the mechanical test plate provides a constant normal stress of around 40 kPa during testing. In contrast, the player testing suggests a peak surface contact stress of around 230 kPa, causing more compression and confinement of the infill (and potentially also the shockpad).

The elastomeric infills and shockpads used in artificial turf (recycled crumb rubber) have recently been investigated at LU, Wang (2013) and shown to behave non-linearly under compressive loading with variable hysteresis and energy return under different load rates. Thus, a player applying higher compressive stresses and lower loading rates compared to mechanical tests would be expected to generate a different material response. How this may affect traction is as yet unclear but could be expected to generate a higher traction through increased shear strength and/or stiffness of the infill providing greater resistance to stud movement. In principle, the possible effect of changes in loading regimes clearly relies on a good understanding of the surface system behaviour – which is still lacking. Recent LU work, Wang (2013), in this area attempted to measure the system stress-strain response during player testing but was limited to the vertical direction under straight line walking and running

movements. In addition to discrete surface vertical deflection from shoe markers, the pressure distribution under the carpet and at the base of the shockpad was achieved through thin film technology and in combination demonstrated the viability of measurement of the ‘whole’ surface response under human loading.

Surface ‘classification’ and description of its physical state, and changes that may occur during testing, arguably represents perhaps the largest gap in knowledge. The lack of a detailed method greatly constrains the value of many previous surface related investigations and is an on-going challenge for communicating current work. In general, the carpet or fiber type may be reported, infill type and in many cases the manufacturer’s recommended infill spread rate. Much research refers to the carpet type as 1<sup>st</sup> 2<sup>nd</sup> or 3<sup>rd</sup> generation. Rarely is there detail relating to the fiber specification (dimensions) and carpet (tufting) specification (e.g. fibers per tuft or stitch rate and spacing). In many cases the infill particle size range is not given nor the infill depth achieved or controlled during any trials. In the field there are added challenges of reporting the moisture state, surface temperature (as opposed just air temperature), and level of contamination (detritus etc.). How important many of these factors are is open to debate and speculation, however, it is suggested that with increasing focus on the engineering behaviour of the systems and mechanisms of interaction there is a complicit need to categorically state all (relevant) factors to converge on understanding of their relevance.

LU work has investigated many of the surface system components for engineering properties in relation to compression, shear strength and resilience, Young (2006) Anderson (2008) Severn (2012) and Wang (2013), illustrating performance changes with regard to changes in design, build and initial state. In Severn’s work (2010) it was shown that the infill net density can be estimated from the placed mass and volume characteristics and with subtraction of the fiber volume from this matrix and that this density changed further under the normal loads of a traction test, for example. These changes in net density influenced the peak traction and vertical stiffness behaviour – and these changes correlated to expected behaviour from laboratory component tests for shear strength and compressibility of the infill alone – albeit qualitatively. However, there exists no framework to promote a consistent universal method for reporting the initial state or the changed ‘state’ during loading (largely due to the low stiffness and high air void particulate infill and porous shockpads).

However, in this and other similar work the fiber to infill interaction has yet to be studied in any detail. It seems prudent to suggest that increased density state and increased confining stress of the particulate infill (under player or mechanical test load) will also mobilize additional restraint to infill distortion and displacement provided by the fiber to infill particle contact interface. This interface frictional resistance (angle) also is expected to increase with increased confining stress and infill particle deformation. It seems prudent to suggest one important step is to study the mass interaction of fibers and infill, perhaps during shear, to observe the zone of influence around a moving stud for example, and develop/refine conceptual models for their behaviour.

### 3. Discussion & Conclusions

The interface between the surface behaviour, the mechanical testing and the athlete is a crucial one of some complexity as discussed in preceding sections with regard performance and safety risk. The ongoing challenge to the collective research communities working in this area is to better establish sport surface science as a coalesced and cognitive framework to which existing research contributes effectively and new research builds the future knowledge and capabilities. It is suggested that as sport, be it professional or leisure, permeates more and more into the social and economic fabric of our society then we need to rise to the challenge of improving the science. It would seem that the surface and the footwear are inexorably linked, and that to date we have a paucity of real understanding of how the surfaces deliver and influence user performance and hence may be also linked to risk.

The current conceptual models of surface materials’ properties, interactions and response to loading regimes need much refinement. However it seems prudent to increase the focus on understanding the in-service requirements from the user perspective, primarily through player testing of key sport specific movements and where possible to extend measurement techniques to measure the surface response. The ‘Loughborough Map’ of the research strands that contribute to a more complete understanding of sport surface science is presented in Figure 1. This will improve the current conceptual models, largely based around mechanical testing results. The improved conceptual model(s) should be ultimately refined into mechanical and numerical models with the power

to extrapolate for a range of user ‘critical’ movements and fine tune component behaviour and estimate the effects. The numerical models have the power, when combined with biomechanical models, to help develop appropriate methodologies for surface testing methods that better replicate the most important facets of the player surface interaction under realistic loading regimes. These tests may, in fact, not replace the routine industry compliance tests in use but would be expected to enhance scientific understanding of the effects of pitch designs and material components on the player biomechanical adjustments and musculoskeletal loading – aimed at higher intensity and higher risk manoeuvres. The enhanced tests would form a more appropriate ‘tool kit’ to support player injury surveillance and perception studies. However, it is our opinion that without better formulation of the specific interaction mechanisms of player-surface interaction and understanding of the relevant surface properties there is little point in incrementally adjusting or developing mechanical tests much further than currently exists. We suggest it is a challenge to our surfaces research community to ensure future research aims to develop and refine conceptual models to a level that fully describes material interactions and the surface system response.

The picture is far from complete however, especially in regard to studying real facilities on site whereby characterising the materials and their state *in situ* is an ongoing challenge. More field studies of surface performance and characterising surface state (and the effects) is vital to ensure laboratory based research programmes are validated and remain relevant to field in-game conditions. Models for surface system ‘degradation’, and maintenance interventions, are a key requirement.

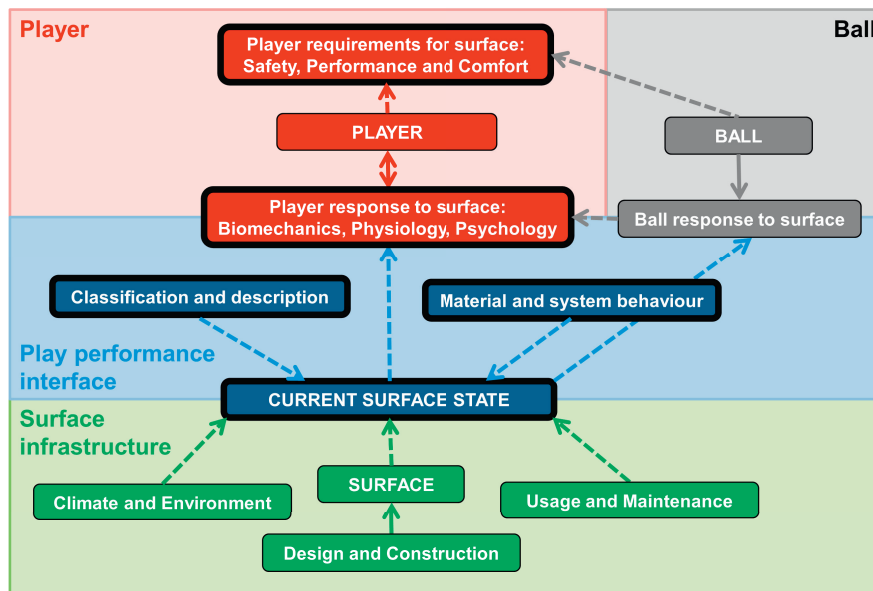


Fig. 1. ‘Map’ of the Loughborough University Sports Surfaces Research Framework for Artificial Turf.

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