TECHNICAL REPORT

FOUNDATIONAL RESEARCH FOR NON-IRRIGATED HOCKEY TURF

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EXECUTIVE SUMMARY

The FIH wish to see elite hockey moving to surfaces that do not require watering, and their vision is to ensure that the playing characteristics of non-watered surfaces have equivalent performance to Global category wet surfaces (or as close as is physically possible).

There are numerous characteristics of a wet hockey surface that are not measured within the current test methods. Previously, it has not been necessary to measure these characteristics as all elite hockey fields are mandated to be wet. It is therefore necessary to understand what characteristics of a wet surface are important for the game of hockey, and to develop new test methods that can provide objective measurements.

The introduction of new validated test methods will facilitate the benchmarking of current wet hockey surfaces, and the establishment of normative profiles and thresholds. Forthcoming innovations in non-watered hockey surfaces will be measured using the new test methods, and it will be possible to assess their equivalence to the current wet surfaces.

This project used focus groups and questionnaires to identify the key game events where the characteristics of a water-based pitch is deemed to be important. This qualitative research identified four key events: 1) ball speed, 2) oblique ball bounce, 3) 3D skills, and 4) stick-surface friction.

Objective measurements of these key events were obtained through player testing using high speed video analysis (on the field) and force plate analysis (in the biomechanics lab). The objective measurements (e.g. speed, angles, distances etc) were used to inform the development of new laboratory test methods to assess the relevant surface characteristics.

Four new laboratory test methods were developed, and a range of Global (wet) and National (dry/sand) surfaces were evaluated to establish normative profiles. Significant differences were found between the surface categories. This foundational research provides the basis for a new global standard for non-watered hockey turf.

1 Introduction

The FIH wish to see elite hockey moving to surfaces that do not require watering, and their vision is to ensure that the playing characteristics of non-watered surfaces have equivalent performance to Global category wet surfaces. Following a competitive tender process, the FIH commissioned a collaborative research project to be delivered by between Labosport (FIH test institute), and Loughborough University's Sport Surfaces Research Group. The research project will be described in this technical report and comprised of four work packages.

Work Package 1 - Literature review

Work Package 2 – Qualitative research on player perceptions

Work Package 3 – Objective measurements of key events/attributes

Work Package 4 – Development of laboratory test methods

2 Work Package 1 - Literature Review

2.1 Literature review introduction

A comprehensive literature search revealed very few directly relevant (academic) publications in field hockey. The search terms utilised with a variety of search engines used descriptors such as - field hockey, turf, synthetic, performance, and player feedback. Publications found showed the work by the Loughborough University sports surfaces group to dominate. This reinforces the direct relevance of previous Loughborough University research on hockey field build quality and performance, and especially player feedback and mechanical testing of elite level, water-based fields (primarily all from work in the 2000s). No recent and explicit (peer reviewed) publications were found relevant to field hockey play performance and player perceptions. Furthermore, no University PhD theses were found (from a review including the USA, Australia and Europe) other than the Loughborough University project by Dr Colin Young (published in 2006).

2.2 Directly relevant published studies

Loughborough University staff authored numerous papers in the 2000s, primarily linked to the then 'World Class Water Programme' Hockey England initiative, aimed to provide strategic support to elite hockey. A related research project, led by Dr Paul Fleming, was partly funded by Sport England and Hockey England (Period 2002-2007). This research included the doctoral studentship programme successfully completed by Colin Young (2002-2006) under the supervision of Prof Paul Fleming and with specific input on player perception from Dr Jon Roberts, both of whom are investigators on this FIH project. A brief overview of the papers provides the following key points:

1. Fleming P. R., Dixon N., Lambert J, Young C, "Monitoring the Performance of Hockey Pitches During Construction", The Engineering of Sport 4, Kyoto, Japan, **2002**, pp. 545-552, ed. S Ujihashi and S Haake, Blackwell.
   Primarily useful to identify the detailed make-up of the Loughborough pitch (at the time) to compare and contrast this design and build with other water-based pitch designs in England. It does not include any player feedback data.
2. Young C, Fleming PR, Dixon N, Jones R, Roberts JR, (2004), Correlating Playing Performance Tests with Human perceptions for Synthetic Field Hockey Pitches, The Engineering of Sport 5, ISEA, Editors Hubbard M, Mehta R, and Pallis J.M., Vol 2, pp517-523. ISBN 0-9547861-1-4.

Correlations between the field test data and players' requirements are highlighted and discussed. The findings show that players were able to identify significant differences between (similar) water based pitches in the premier league. The 'ideal' or preferred playing characteristics were obtained along with their relative importance. Conclusions included that surface pace and ball bounce were the most important characteristics to the player.

3. Fleming P, Young C, Dixon N, (2004) Performance Measurements on Synthetic Turf Hockey Pitches, The Engineering of Sport 5, ISEA, Editors Hubbard M, Mehta R, and Pallis J.M., Vol 2, pp524- 531. ISBN 0-9547861-1-4.
   A study of synthetic pitches used for field hockey, evaluating many aspects of their design and construction and in-play performance from mechanical tests. The data showed relatively wide variability across pitches and between pitches, especially for hardness/shock absorbency, and concluded the test results were affected by surface water quantities and uniformity of watering.

4. Young C, Fleming PR, Dixon N, (2006), Test Devices for the Evaluation of Synthetic Turf Pitches for Field Hockey, In: The Engineering of Sport 6: Proceedings of the 6th International Conference on the Engineering of Sport (eds E.F. Moritz & S.J. Haake) Vol. 1, pp. 241-246, Springer.
   This paper presents results from a comprehensive program of testing on six world class synthetic turf pitches used for field hockey. The ball interaction tests, vertical ball rebound and ball roll, were found to be significantly influenced by environmental factors such as moisture and wind.

5. Severn K, Fleming P R, Dixon N and James I, 'Temporal and Spatial Investigations on Water Based Hockey Fields', Presented at the International Conference 'Sport Technology and Research into Sport Surfaces – STARSS', CD-ROM, Loughborough University, September 2007, editors Fleming PR, Carre MJ, Dixon SJ and James I.
   This paper arose from the MSc study of K Severn, and extends the information and insights of the WCW/Colin Young work, specifically around wear, maintenance, and variation in traction behaviour across pitches over a period of 3 years. The findings of the research showed several contributing factors combined with age that influenced changes in the mechanical behaviour of the pitches tested. Those pitches with high levels of usage showed deterioration in their mechanical behaviour. Pitches that were well maintained better sustained their mechanical behaviours. Compaction of the carpet pile was determined to be the greatest cause for changes to the mechanical behaviour of a pitch and is considered dependent on both levels of usage and maintenance factors.

6. Fleming, P.R., Young, C., Roberts, J.R. et al. Human perceptions of artificial surfaces for field hockey. Sports Eng 8, 121–136 (2005). https://doi.org/10.1007/BF02844013
   This paper describes the interviews of 22 hockey players, to build a 'structure relationship model', by inductive reasoning, which maps the key feedback themes that arose from players' perceptions. Subsequently the themes and language identified were used in the design of specific questionnaires around player preferences and importance ratings.

2.3 Review of PhD Research Thesis, by Colin Young (2006) "The Mechanical and Perceived Behaviour of Synthetic Turf Field Hockey Pitches"

In brief, the thesis describes packages of research work. This includes for player feedback 22 one-to-one player interviews, and questionnaires to 400 players (204 returned) to collect the players' rating of 'importance' and 'preferences on performance' in relation to water-based pitches (using a Likert scale of 1-7 for scoring). It contains the full details of mechanical testing of 6 elite level pitches in England, the Loughborough University hockey pitch in more detail (including further laboratory-controlled testing), and notably includes measurement and evaluation of surface water quantity on the mechanical test results (but not for not player feedback). A comparison is made of the player feedback rating to the mechanical surface testing data, for the 6 elite level water-based pitches, in England. Players were interviewed and questionnaires undertaken, however data collection by focus groups was not utilised.

Overall, in the player preference questionnaire, the playing characteristics with highest scores and ranked as most important were 'surface consistency', linked to irrigation, and the 'ability to demonstrate deft skills'. Given the choice, most players stated they like to play on a fast low bouncing surface conducive to deft stick work with high underfoot grip, no ball spin and with moderate hardness.

Good correlation was found between the (averaged) player perception scores and the (averaged) mechanical test data for ball rebound (bounce), underfoot traction and surface hardness. Of note was that player perception of pace did not correlate well with ball roll distance measurements.

A large variation in the mechanical test data was observed between the six pitches, linked to variations in the construction specification and carpet & shockapad design. The variations in shockpad thickness showed a strong influence on hardness and ball rebound and was further supported by the controlled laboratory testing.

The effects of the amount of water on the Loughborough University pitch was investigated in detail, and showed a real effect especially on lower energy impacts such as ball rebound, and the hardness recorded from the (lighter) 0.5kg Clegg Hammer. In addition, a reduction in the peak rotational traction values was observed for increased wetness.

3 Qualitative research on player perceptions

3.1 Focus groups overview

Three semi-structured interviews with focus groups were conducted. The interviews were performed on Microsoft Teams. The interviewer guided the discussion by pre-defined open-ended questions but went into more detail regarding specific topics that were introduced by participants. The transcripts generated by Microsoft Teams were used to conduct further analysis using the qualitative data analysis tool NVivo. Previous work on perception of football surfaces provided a framework that was used for a deductive analysis (Roberts et al., 2020). The transcripts were therefore analysed so that various quotes of interest were assigned to pre-established themes.

Table 1. Description of participants in the three focus groups

FG	Gender	Number of participants	Age	Team	League	Typical Surface
FG1	M	3	20.5 ± 0.5	Loughborough University	Midlands Premier League	Mixed
FG2	F	2	21.5 ± 0.5	Loughborough University	International	Water-based
FG3	M	6	20.8 ± 1.3	U21-23 International	International	Water-based

3.2 Focus group main findings

A summary of the key themes covered is given in black font. The corresponding key quotes that support the claims are given in blue italic font.

Ball speed	Water-based surfaces are perceived to allow a quicker, more agile game, whereas sand-based surfaces slow down the ball and do not allow the same speed and agility. The speed of the game seems to be a key feature of water-based surfaces that makes playing on it more enjoyable: *"[…] the ball genuinely just glides a lot nicer along a water-based pitch. […] it will be much more fast paced because the ball is travelling quicker."* *"I much enjoyed a faster game where the ball is fizzing around the [water-based] pitch and it just looks much nicer in the eye and it plays much nicer. It's much more enjoyable."* *"It almost looks like the ball is picking up speed like after the first kind of bounce."* *"It almost feels like it gains power and speed. It will bounce and then just fly at you […] Whereas on a sand-based [pitch] just all of the power […], it just dies so quickly."* *"I think the faster pace makes the game probably more attractive as well because you can play those difficult balls and it's more likely to be successful."*
	FG2, however, disagreed with increased ball pace due to water-based pitches and mentioned that games on sand-based pitches would be even faster, but less skills could be executed, and it would be less enjoyable: *"I mean the game is very fast at all senior international level and all of that on a water-based pitch. I think the game would probably be faster on a sand-based pitch, but I don't think it would be good to play on."* *"On a sand-based. It would probably be a much more passing game because the ball moves quickly, and you wouldn't be able to execute skills probably as well as you would like."*
	Water-based surfaces allow quicker and more accurate passing with less interceptions and at the same time allow more counterattacking *"On a sand-based pitch […] a counterattacking opportunity can sort of die out. […] just from the ball moving slow. […] whereas on a water-based pitch, if you're giving the ball a good speed, it will stay there and you can get from end to end in seconds and it really does make a difference."* *"whereas on a water-based, I know that if I've a thin gap I can get it there because the ball will travel quick."* *"I have to really hit this as hard as I've ever hit it before and get an inch perfect, whereas on a water base I kind of know that as long as I get good contact that that ball will fly through that gap and I should be fine."*

Bounce	Water-based surfaces seem to require players to be more skilled and to anticipate the ball bounce. Increased bounce is perceived positively since it makes the game more interesting, challenging, and competitive and exposes the differences between skilled and less skilled players more directly

	"[…] a sand-based or [sand]-dressed pitches are a lot more forgiving for the players with poor technique. If you play a pass and the ball starts to bounce on a sand-based or [sand]-dressed pitch, [the ball] usually starts to die out after the first kind of bounce, whereas if your technique is poor on a water-based it will continue to bounce, then you will be penalized for that." *"I think definitely on a water-based pitch […] it increases the gap between players, so it really shows up the good players from the best players […] whereas on a sand-based pitch they might look similar standard."* *"I think it's harder, if it doesn't stop, if it carries on bouncing, it definitely adds an element to the game that it wouldn't otherwise, because I mean personally, if I'm throwing an aerial when it's bouncing, I literally have to concentrate so hard trapping it […] whereas on a sand-based if it bounces, you know that it's going to be relatively flat by the time it gets to you, so you can almost plan the next sort of skill from that. So I guess maybe it's like a higher skill level too on a water-based pitch to have to trap it and then move off there."* *"But I quite like a bit of a bounce. It plays a bit quicker."*

3D skills	Another perceived key benefit of water-based surfaces is the allowance of more 3D-skills *"You just have way more options of getting the ball up in the air and using the surface to advantage."* *"General 3D skills, I suppose, on a water-based pitch are far easier to do compared to a sand-dressed or a hybrid. Just simply off the fact that the bounce off the pitch that you can use to manipulate the way the defender would want to look at the ball."* *"It definitely makes the game a little bit more exciting. I think on a sand-based [pitch] the game would be quite dead […] you see a lot more 3D skills and stuff [on water-based surfaces] and I think you would miss a big part of that from the game if it was purely sand-based."* *"So because the surface is a lot more bouncy […] certain skills come off a lot cleaner on a water base. So one skill is almost like a squeeze skill. So it's where you can press the ball into the surface and it pops back up and you can use it to sort of gently squeeze it over a defender's stick."* *"[…] the water-based pitches are actually quite soft […], it's a lot more bouncy, sort of reactive pitch which I think is more enjoyable for players with 3D skills […]. That comes into play a lot more on the water-based pitches."* *"I think that getting under the ball is a lot easier on a water base, so whether that's hitting a goal, lobbying a little slice underneath. It's all easier 'cause you got a little bit of push from the turf. […] So if you're hitting on a flat sand base that doesn't really have any give could be quite tough to get underneath it [the ball]."* *"On sand-based pitches – you find a lot more passing games. There's not much 1-V-1 skill that goes on especially at the higher level, whereas I think I know a lot of boys that play on water bases in the club that would happily engage if they are in a 1-V-1 situation on a water base."*

Stick-surface interaction	Drag Flicks / injections are easier on water based pitches *"In the short corner, like a drag flick, that's the common way of scoring from top of the D. […] Like good level or like even medium level hockey players, that can drag flick, would say that drag flick is so much more enjoyable and requires a bit of like less effort because you can just pick the ball up, glide across the surface and fling it towards the goal, whereas on a sand-based pitch having to really put a lot more pressure and force into dragging it […]."* *"It's like the angle of the stick on the ball. So like it's almost like it's in your hook when you do it. So the ball is behind you. Some people either setup stationary, so the ball will be behind them on the line and their feet will be, one foot will be behind the line and one that would be like pointing towards the target. Or you can kind of step into it, but the ball will always kind of start from heights you like, kind of like drag it on the floor and you like kind of whip it. Obviously if it's dry the ball can often like get stuck on the pitch because you're going so quickly from that first transition like to release the ball if it's dry. It tends to like people either like to roll over the ball and like misinject it, whereas if it's wet it's a lot smoother to do it."*
	The possibility of executing more skills on a water-based surface is also affected by the interaction between the stick and the surface. While there seems to be extensive friction and resistance on sand-based surfaces, the stick seems to glide through the surface much nicer on a water-based surface, allowing more versatile movements and pace: *"So if that's like the sand pitch surface, the sand gets scraped from this section and sort of builds up in-between your stick and ball and so it can like alter how the ball comes out and makes it a lot slower because the sand that gets on the ball, whereas with the water-based [surface], the water is just moving out the way. And it's not staying there, so it just kind of glides through and you can get much more of a like whip and like a fast injection."* *"It's the angle and stick on the ball. Like if it's dry it is a lot slower and that's when the ball […] bubbles over the back of the stick […], which is an absolute nightmare."* *"I think the big one is when you're dragging the ball from right to left. Just the nature of the skill, it kind of tends to get stuck under. I often find like the stick will almost roll over it, 'cause it's just too much friction with the ball in the turf. And then you're not leaving it behind you and you normally just get tackled or turn it over."* *"When you're doing your skills [on a water-based surface] it doesn't stick to anything. It's just, it feels a bit, just feels smooth."*

Grip (shoe-surface)	One potential disadvantage of water-based surfaces could be reduced traction due to wet conditions, but it was mentioned by the participants that such wet conditions are desirable for the game and that they could be overcome by appropriate footwear *"[…] to run and slide on a sand-based pitch, I'll get stuck after like a metre. But if you've got a lot of pace and you get a good dive, you can travel for 2-3 metres on the water-based and slide the whole way, so it just enables more options in the game."* *"[…] some sort of plastic, so that will dig into the fibres of the top layer of the pitch. And that gives you that traction."*

	"It is almost entirely dependent on the footwear that you bring to the game." *"I think grip is quite important. So if you're on your feet you wanna have like good grip. But if you want to do like a sliding intercept, you obviously don't want to get stuck."*

Skin injury	Water based pitches allows more intense movements to be made, such as diving or lunges that could even lead to strategies generating more goals *"Yeah, so often in hockey a lot of goals are scored through deflecting the ball and sometimes, well, the game is often played a lot quicker, quicker on a water-based pitch. […] you see quite a few more deflections. People are able to sort of slide across […], able to sort of lunge a lot further than they normally would. […] being able to slide opens up a lot more opportunity there."* *"… diving deflections and stuff like sliding on their shin pads or like on the side or like even, just like plunging towards the ball just to get a touch towards goal. I feel like it wouldn't be as inviting on a dry pitch to do."* *"Yeah, I think surface-related, abrasion is definitely the key one. […] even a dry water base will be more abrasive than a wet water base, but it's still nothing compared to a sand-based pitch. It's just not fun to fall over on a sand-based pitch. It really does sting."* *"Abrasions […] are the key one that will happen. Commonly every game at least a couple players on each team. Not so much on a water base. You'll still get a slight bit of redness on the skin, but it's certainly a lot more forgiving."*

Hardness and injury	The hardness of sand dressed pitches was identified as a potential injury risk for lower limbs *"Sand-based pitches are a lot harder. So like in the long-term, like on the knees, it's definitely not as good as water-based, which is a lot more springy."* *"Impact through the legs I've suffered from shin splints a couple times. But then again. I can't find the difference in the surface […]. I'm not sure if I could attribute that to the surface."*

Fatigue	Water-based surfaces are associated with higher fatigue *"I find it quite like almost tiring to play on [water-based pitches] because it's so spongy and it's quite dense. I personally find it hurts my calves more because you're just like having to compensate for that sponginess. The whole time."* *"You don't want it to be too soft because then it like is heavy on your legs when you're running. So like, for example, there's some pitch that you play on where it actually feels harder because it like takes a lot of energy out of you."* *"I actually think you get tired faster on a water base. But I think that's just because of the increase in the way the game is played. So I think because it's a faster game, you're doing a lot more short, sharp sprints."*

Changes over time	Water-based surfaces also seem to be more heavily affected by age. While they can be too bouncy and grippy at the beginning, they often lack traction when old *"So with the bounce specifically, a brand-new water-based is super bouncy."* *"[…] when you first build a water-based you need to give it like a year or so […] because at the start it's too reactive, it's like overly bouncy and overly sticky."* *"Yeah I think as a water-based gets older it loses a lot of like friction and stick."*
	FG2 - water-based pitches tend to be more variable, especially during extreme weather conditions *"[…] with water-based pitches it's more like: Oh, that one's really bouncy, or that one fast, that one slow and well, I wouldn't say that was necessarily the case for non-water-based pitches."* *"[…] it would be like patches of [water], like a water-based could get quite dry and then patches are still wet and it's like, it's just, it's kind of annoying.* *"In the colder times of years when the water-based pitches start to freeze up or get a little colder, you can get bit more slippy. […] it can cause bad injuries."*

To summarize, hockey players seem to prefer fast, wet surfaces that allow a quick, agile game and that allows skilled players to excel with their superior technique and specific 3D-skills. At the same time, the surface should not be abrasive so that injuries can be avoided. More constant conditions over time would be desirable. Potentially negative associations with water-based surfaces are often attributed to secondary parameters. Some hockey players could be prone to the halo effect, rating each individual attribute better just because of their overall higher preference for the surface.

3.3 Questionnaire overview

A questionnaire was developed to validate the findings of the focus groups with a wider international group of hockey players. The online questionnaire was distributed to elite hockey players and support staff via the FIH prior to the Toyko Olympic Games. The questionnaire received 232 responses from players around the world (30% Europe, 20% India, 20% South Africa, 15% North America, 10% Asia-Pacific, 5% other). The questionnaire received a well-balanced response in terms of gender, playing position and experience.

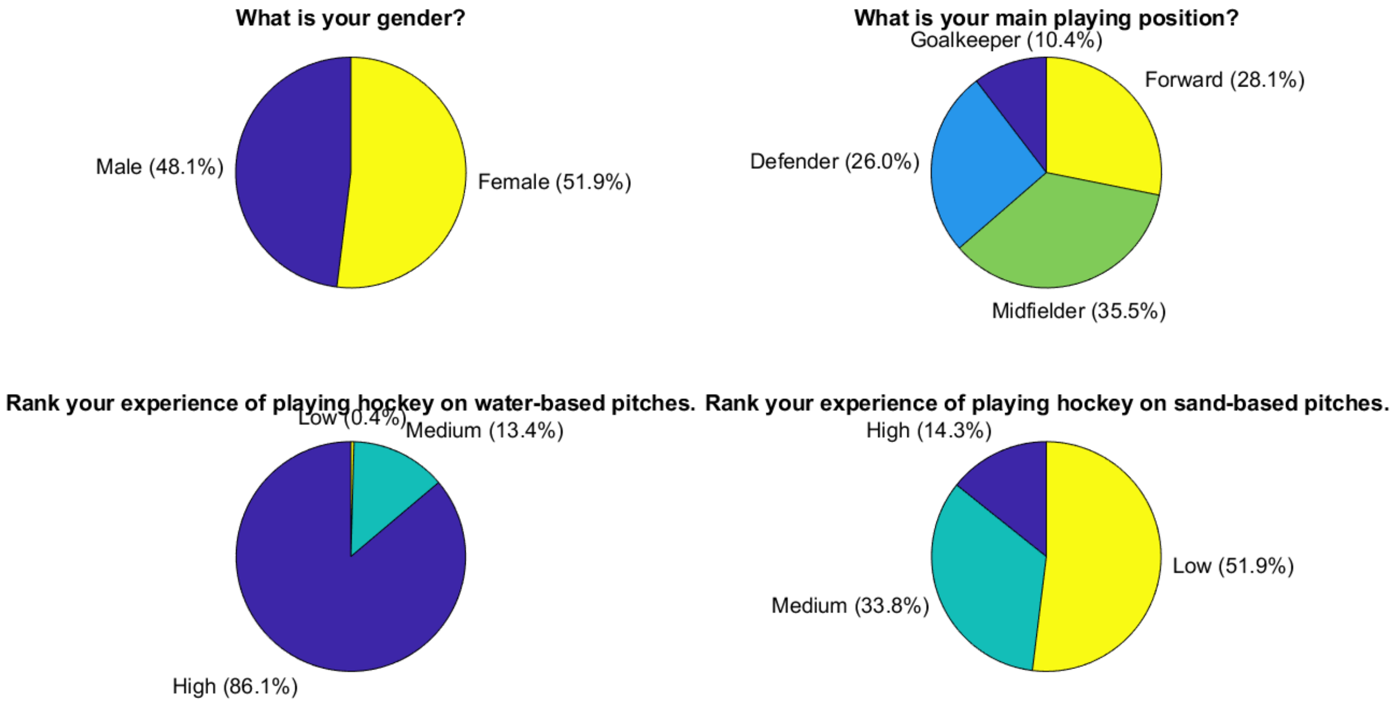

Figure 1. The balance of respondents to the questionnaire

3.4 Questionnaire findings

The questionnaire comprised of five questions with an agreement/disagreement scale, plus an additional multichoice question on ball bounce. The results showed an overwhelming agreement ('strongly agree' and 'agree') to the following statements.

1. *The ball can be **passed at greater speed** on a water-based pitch resulting in a faster game.*
2. *Water based pitches allow me to perform **3D skills** more frequently and successfully than on a sand-based pitch*
3. *On a water-based pitch, I can perform a **drag flick more successfully** because the stick glides smoothly on the surface.*
4. *On a water-based pitch I am more likely to go to ground (slide/dive) on the surface as the **risk of skin injury is lower**.*
5. *The playing performance of water-based pitches is **consistent and predictable**.*

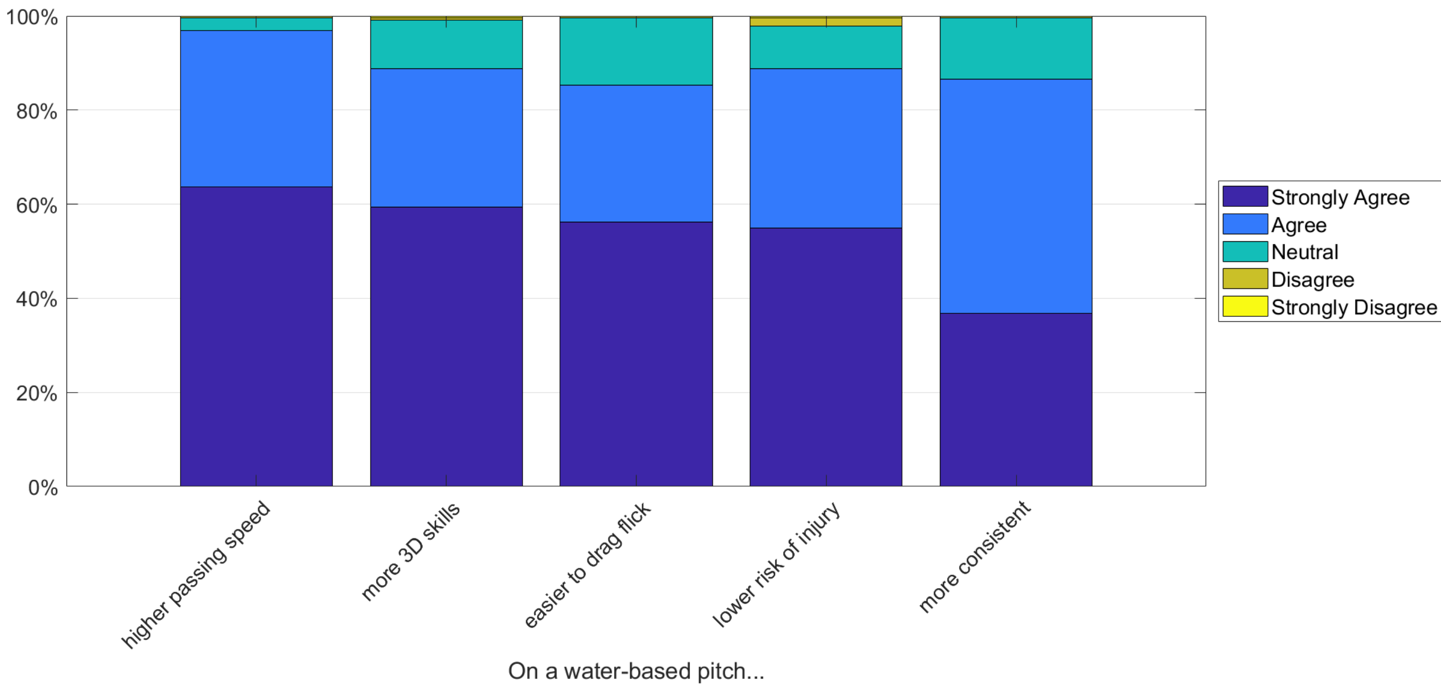

Figure 2. Results of the questionnaire.

The additional question on ball bounce returned a more complex set of results with different countries reporting a very different experience, or interpreting the question differently.

During match play, how does the ball bounce on a water-based pitch?

- *A longer bounce requiring skill to control the ball.*
- *Neutral (same as sand-based pitches).*
- *A shorter bounce that is easier to control.*

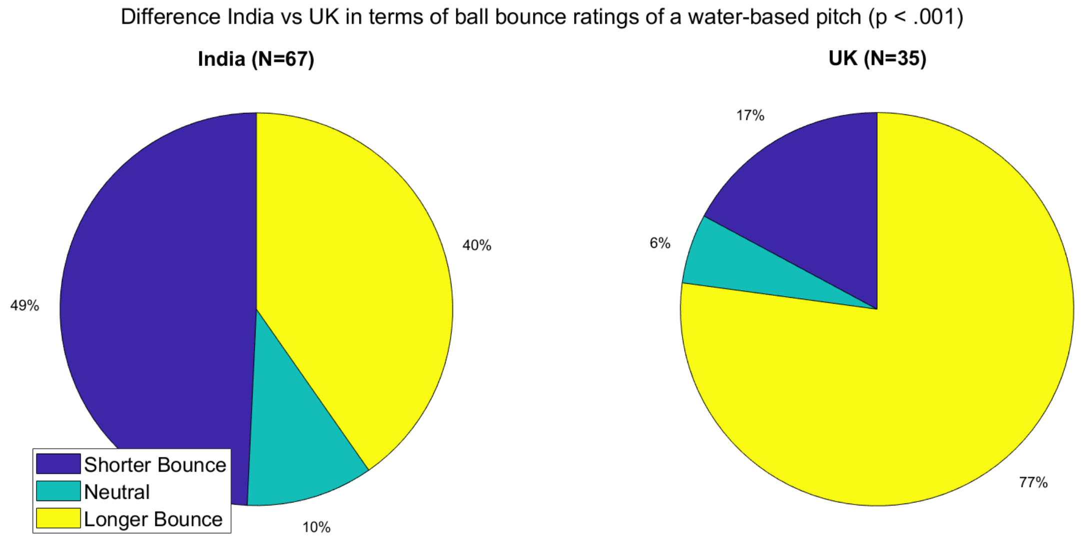

Figure 3. Differences in response to the ball bounce question.

3.5 Qualitative research conclusions

The qualitative research provides the foundation to identify the key game events where the characteristics of a watch-based pitch are deemed to be important. The dominant game events/attributes were determined to be;

1. ball speed;
2. oblique ball bounce;
3. 3D skills;
4. stick-surface friction.

These dominant game events/attributes form the focus of the subsequent work packages; however, it is important to recognise that the qualitative research did identify other relevant topics. The narrative responses from the player questionnaire are an especially rich source of information should a need arise to investigate additional game events/attributes.

4 Work Package 3 - Objective measurements of key events/attributes

Objective measurements of the identified dominant game events/attributes were obtained during a series of testing sessions with Loughborough University men's first hockey team. Numerous players in this team have experience of playing hockey at the highest international level. The testing sessions were conducted on a water-based pitch that had been watered to match play conditions. Additional testing was conducted within the Sports Technology Institute laboratories. The purpose of the player testing was to obtain the 'boundary conditions' for the different game events/attributes to inform the design of the laboratory test methods (speeds, angles, loads, distances etc)

4.1 Ball speed

Fast ball speed was identified as a key attribute of water-based pitches. A 'slap shot' for a long pass is a relevant game event to measure as the surface will have a greater effect on ball speed over longer distances.

The initial ball speed from slap shots were measured from three different players. Measurements were obtained from calibrated high-speed video footage operating at 1,000 frames per second. The camera was located close to the ground, and perpendicular to the ball direction to avoid parallax errors.

Figure 4. A video-still from the high-speed video footage of a 'slap shot'

Table 2. Initial velocity results for the slap shot long pass

	Player 1	Player 2	Player 3
Initial slap shot velocity (m/s)	26.7	15.2	21.2
	23.4	15.9	22.6
	23.3	14.1	20.1
Mean (m/s)	**24.5**	**15.1**	**21.3**

4.2 Oblique ball bounce

Oblique ball bounce was identified as an important characteristic of water-based pitches. The oblique ball bounce from a high pass was determined to be a relevant 'in game' event.

The oblique ball bounce dynamics from a high pass slap shots were measured from one individual player. Measurements were obtained from calibrated high-speed video footage operating at 1,000 frames per second. The camera was located close to the ground, and perpendicular to the ball direction to avoid parallax errors.

Figure 5. A composite image of the high-speed video footage of an oblique ball bounce

Table 3. Incoming oblique ball bounce dynamics

	Speed (m/s)	Angle (deg)
Incoming oblique ball bounce dynamics	13.7	45.6
	14.0	45.7
	11.6	47.0
	14.4	38.2
	12.8	44.1
	14.2	44.7
	16.4	43.9
Mean (m/s)	**13.9**	**44.2**

4.3 3D Skills

The ability to perform 3D skills was identified as a key attribute of water-based pitches. The term '3D skills' encompasses a range in game events, but it generally relates to the ability of a player to lift the ball from the surface in order to play the ball in vertical space (aka the 3rd dimension). A relevant 'in-game' event is when a player's stick hits a ball into the surface, and the ball 'pops' into the air.

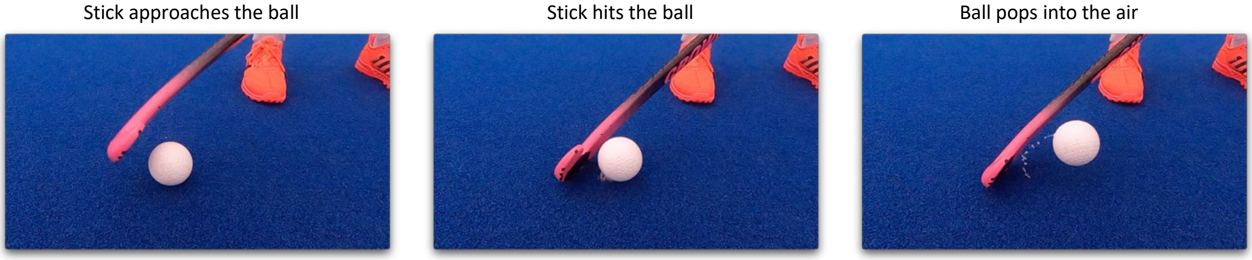

Figure 6. An example of 3D skills where the ball is hit into the surface and then 'pops' into the air.

Players were asked to perform this 3D skills event, and high-speed video was used to record to the dynamics. Analysis of the video footage shows that the ball is initially compressed into the deformable playing surface, and then the ball bounces out of the deformed impact crater. This analysis reveals that the stiffness of the playing surface (magnitude of deformation under load) is an important characteristic for 3D skills.

Loughborough University gathered biomechanics data from a skilled player performing this 3D Skills movement on a force plate. A Global hockey turf system in a wet condition was located on top of the force plate, and tests were conducted with two different shock pads (in-situ E-layer 10mm, in-situ E-layer 20mm)

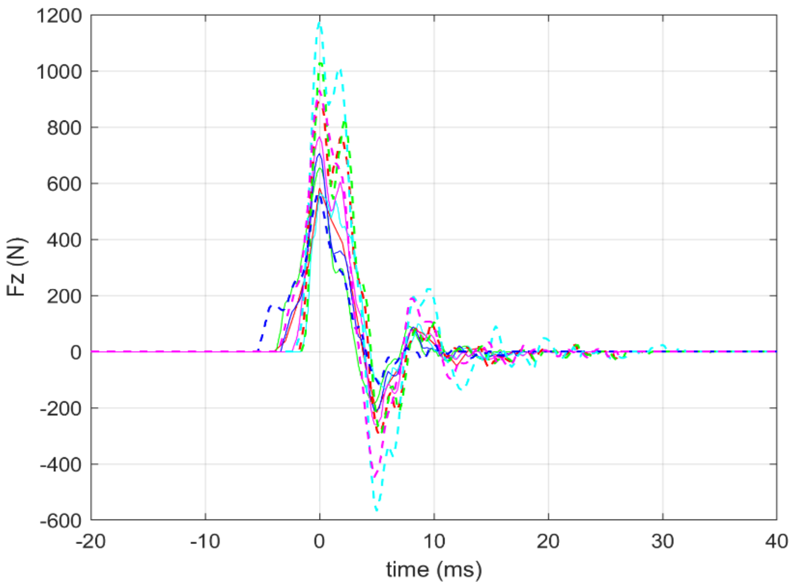

Figure 7. 3D Skills force plate data

The force plate allows for the measurement of the peak force imparted to the surface, and the contact time of the impact event. The table below summarises the results.

Table 4. Results from the 3D skills force plate tests

Trial number	Shockpad	Fzmax (N)	Contact time (ms)
1	EL15	583	22.0
2	EL15	655	19.6
3	EL15	706	21.8
6	EL15	766	22.8
	Average	678	22
10	EL10	888	27.6
12	EL10	566	21.8
13	EL10	1179	33.8
15	EL10	930	29.6
	Average	891	28

4.4 Stick-surface friction

Stick-surface friction was identified as an important characteristic of water-based pitches. In hockey, there are a number of 'in-game' events when stick-surface friction is important, most notably 'injections' and 'drag flicks'.

The dynamics of injections and drag flicks were measured from two international players who specialise in these techniques. Measurements were obtained from calibrated high-speed video footage operating at 1,000 frames per second. The camera was located close to the ground, and perpendicular to the plane of motion to avoid parallax errors.

Figure 8. A video-still from the high-speed video footage of an 'injection'

The high-speed video footage was analysed to measure the dynamics of the hockey stick. A virtual marker was placed on the toe of the hockey stick, and this point was tracked using an automated algorithm.

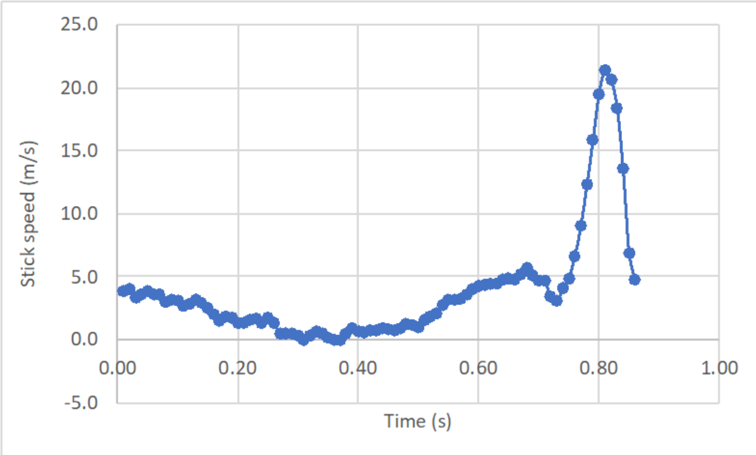

Figure 9. The speed profile of the toe of a hockey stick during an injection

Considering the case of an injection, the stick is in contact with the surface for approximately 2 metres, and the movement has two key phases;

1. The stick initially progresses along the surface with a fluctuating speed with an approximate average velocity of 2 m/s.
2. The stick rapidly accelerates as it is whipped into the air with an average maximum speed of 21 m/s.

Further experiments were conducted within a biomechanics laboratory to determine the load that a player applies to the surface during an injection (and other shots). Hockey turf was laid on top of a sensitive force plate, and an experienced player performed simulated shots. The force plate measures applied load in vertical, and horizontal directions with a high frequency sample rate.

The biomechanics laboratory experiments revealed that the average peak vertical force applied to the surface through the stick during an injection is 58 N (equivalent to 5.9 kg).

Table 5. Force plate data for simulated injection shots (peak forces)

Trial no.	Action	F vertical (N)	F horizontal (N)
1	injection	53	37
2	injection	51	32
3	injection	76	55
4	injection	63	42
5	injection	52	33
6	injection	54	38
	Average	**58**	**39**

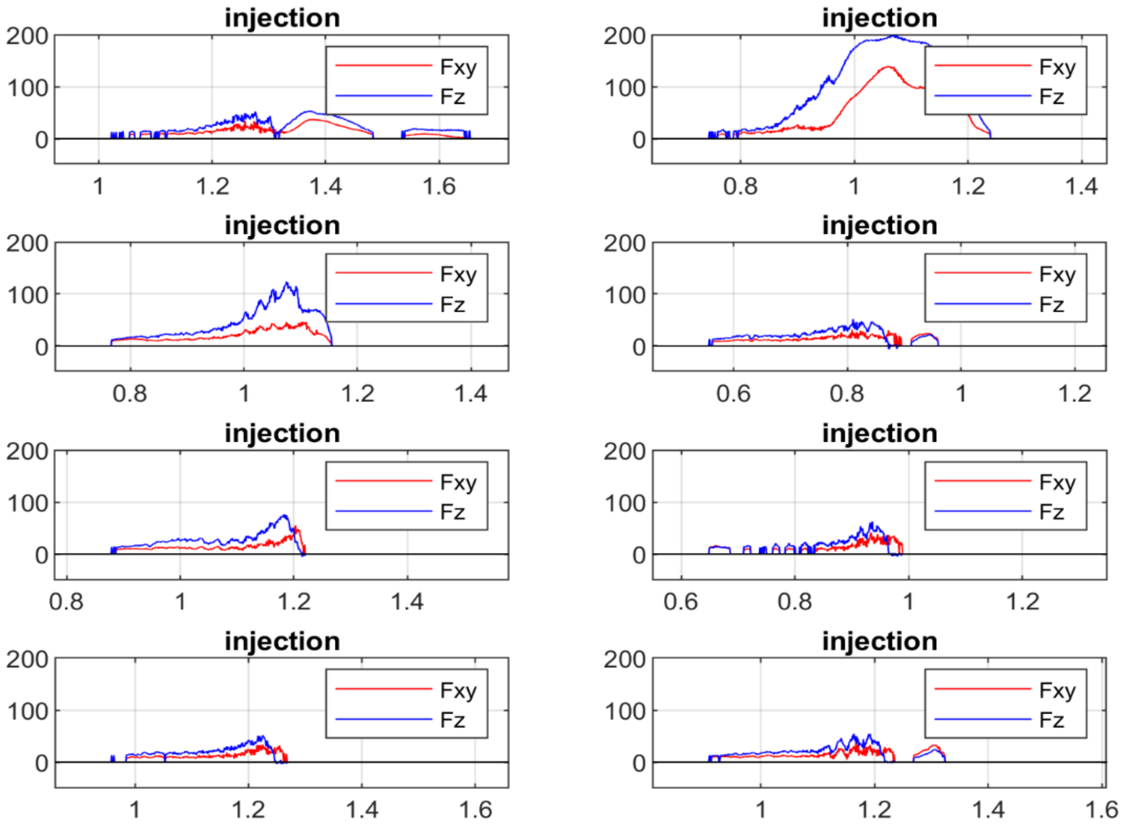

Figure 10. Force plate data for injection shots

5 Work Package 4 – Development of test methods

5.1 Ball speed test

A test method was developed to assess how the speed of a hockey ball changes due to interaction with the playing surface during a high-speed event such as a long pass. Importantly, previous research (Colin Young PhD 2006) found that standard ball roll tests do not correlate to player perceptions of ball-surface speed.

An air cannon is located on the playing surface and launches a hockey ball horizontally at 15 m/s. The vertical distance from the bottom of the hockey ball to the playing surface during the launch event is just 1 cm, and the ball leaves the air cannon with negligible spin.

Two pairs of infrared timing gates are placed on the playing surface to measure the ball speed at two locations; 1) initial ball speed, 2) final ball speed. The initial ball speed is measured at 1 metre from the air cannon, the final ball speed is measured at 15 metres from the air cannon. The results are expressed as 'percentage ball speed retained' whereby;

$$\%\ ball\ speed\ retained = \frac{Speed\ final}{Speed\ initial} \times 100$$

Carpets are thoroughly washed to remove potential effects of residual spin oils. Global systems are watered with 1 litre of water per square metre immediately prior to the test. To account for any potential directional effects of the yarn, each carpet is tested with five repeats in one direction, and five repeats in the other direction. The average of all 10 repeats is calculated.

Figure 11. The experimental setup for the ball speed test

The hockey ball is observed to skip along the surface through shallow bounces. The ball slows as it progresses along the surface, and will eventually initiate a roll. A test distance of 15 metres was selected as this distance is the longest practicable test distance within a laboratory (and for the supply of test samples from manufacturers). The test speed of 15 m/s was selected as this relates to the objective measurements of players (see Table 2), and this speed was found to provide a greater discrimination between playing surfaces.

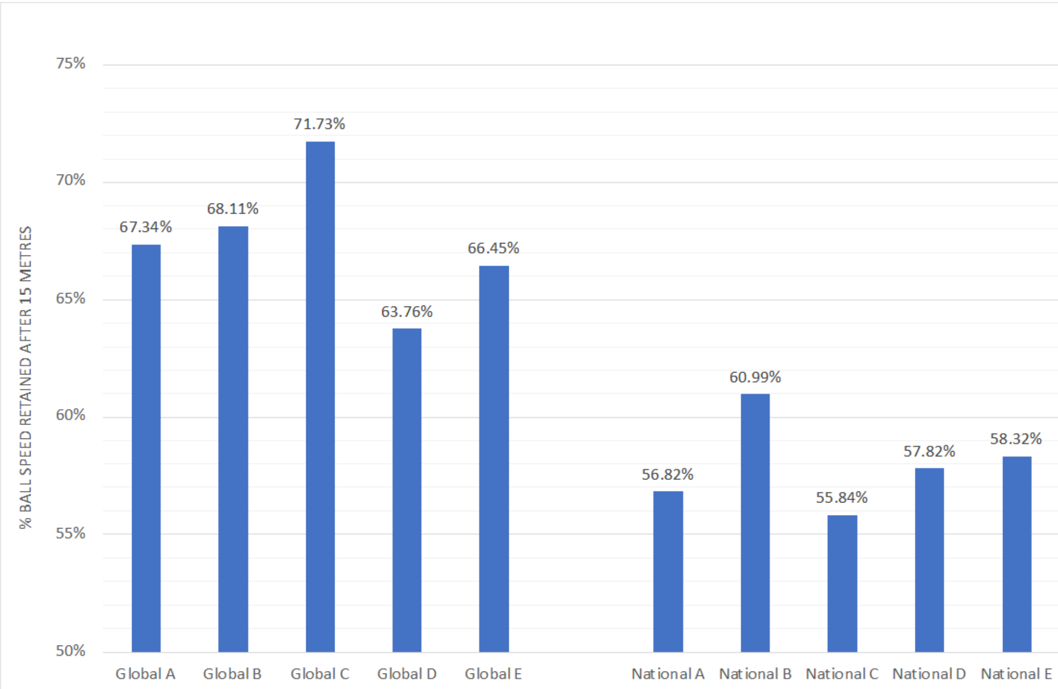

Figure 12. Results of the ball speed test

Ten hockey surfaces were tested for ball speed. The data set comprised of five global systems (wet), and five national systems (sand-based/dry). The results show a clear difference in the ball speed performance between global systems (wet) and national systems (dry). The ball retains a significantly higher percentage of its speed on a global system in comparison to a national system. This result confirms the player feedback that 'water-based pitches provide a fast playing surface'.

5.2 Oblique bounce test

A test method was developed to assess the oblique impact behaviour of hockey balls on hockey surfaces.

An air cannon is used to launch a ball onto a hockey surface (including shockpad) with a speed of 14 m/s and an angle of 43 degrees. These boundary conditions relate to the impact dynamics of a long pass as per Table 3. The ball should exit the air cannon with negligible spin.

High speed video (1000 fps) is used to capture the impact event, and videogrammetry techniques are used to track the trajectory of the ball, before and after impact. Gauss's method of least squares is used to calculate the average speed and angle of each trajectory.

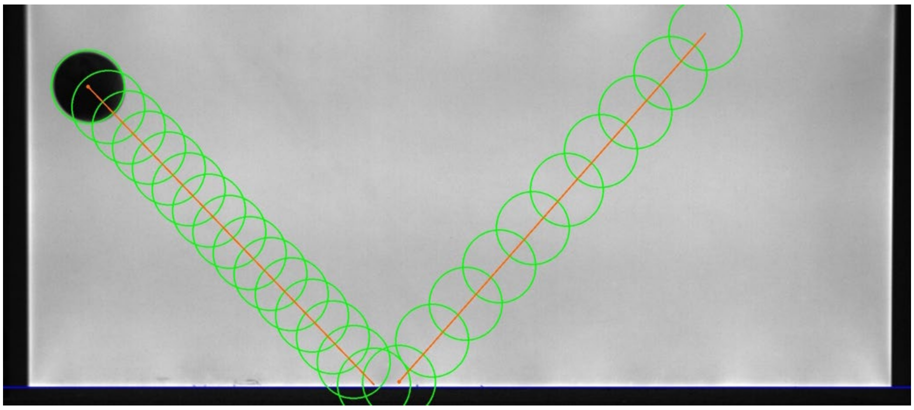

Figure 13. An example of the high-speed video footage and videogrammetry measurements

The results are expressed as 'Pace' and 'Rebound Angle' whereby;

$$\%\ Pace = \frac{Rebound\ speed}{Impact\ speed} \times 100$$

Carpets are thoroughly washed to remove potential effects of residual spin oils. Global systems are watered with 1 litre of water per square metre immediately prior to the test. To account for any potential directional effects of the yarn, each carpet is tested with five repeats in one direction, and five repeats in the other direction. The average of all 10 repeats is calculated.

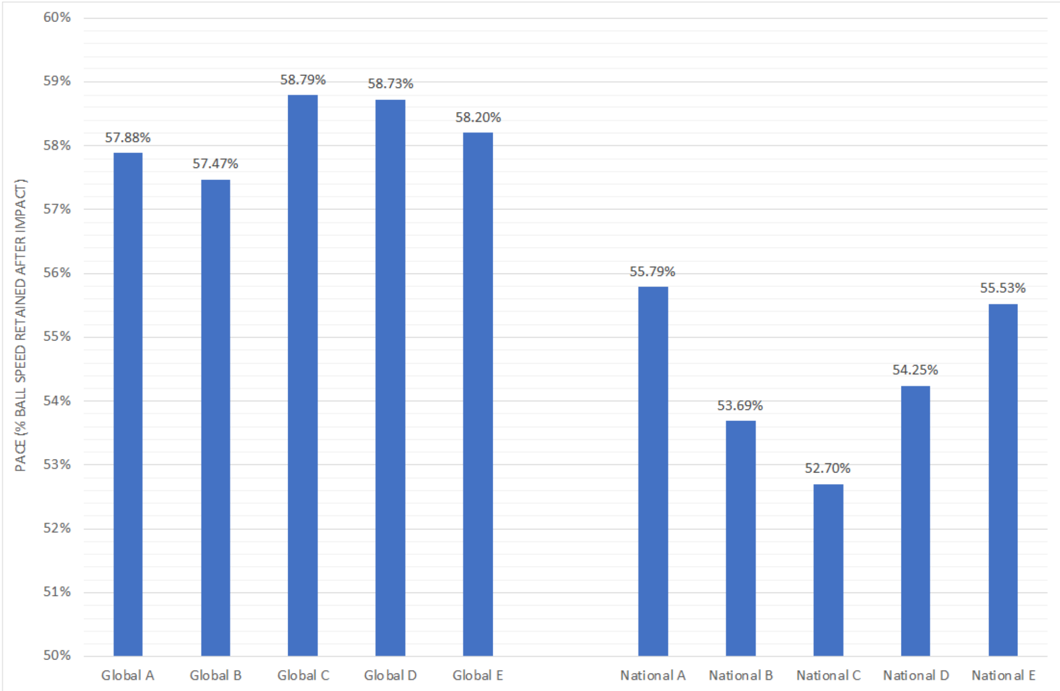

Figure 14. 'Pace' results from the oblique ball bounce tests

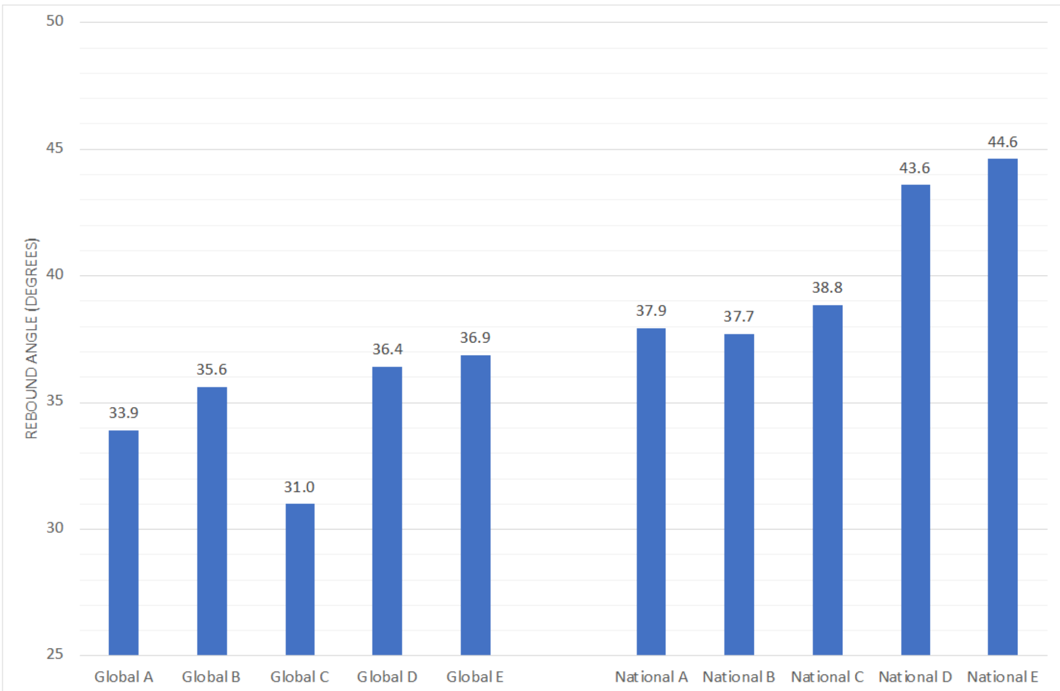

Figure 15. 'Rebound Angle'' results from the oblique ball bounce tests

Ten hockey surfaces were tested for oblique bounce. The data set comprised of five global systems (wet), and five national systems (sand-based/dry). The results show a clear difference in Pace and Rebound Angle performance between global systems (wet) and national systems (dry). During an oblique impact, ball Pace is significantly higher on a global system in comparison to a national system. Conversely, during an oblique impact, Rebound Angle is lower on a global system in comparison to a national system.

An analysis was undertaken to further understand the difference in ball rebound behaviour between global and national hockey surfaces. A trajectory model was developed to simulate the average ball rebound flight path on global systems, and on national systems.

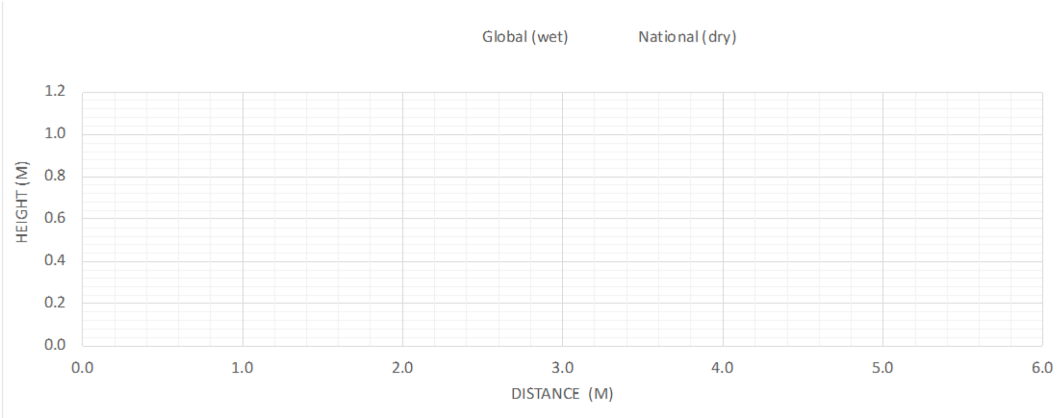

Figure 16. Trajectory simulations to compare ball rebound on global and national hockey turf

The trajectory simulations show that a global hockey surface will provide a faster and lower ball rebound in comparison to a national system. Although the 'Rebound Angle' on a global system is lower, the faster ball speed results in a longer bounce. This objective result confirms the player questionnaire feedback (Figure 3).

5.3 3D Surface Stiffness

A modified AAA was used to simulate the dynamic loading of the hockey surface during 3D skills. Through a process of experimentation, a close approximation of the force plate data (see section 4.3) was achieved by dropping a reduced 10 kg AAA impact mass from a height of 20mm (standard AAA drop mass = 20 kg, standard AAA drop height = 55mm).

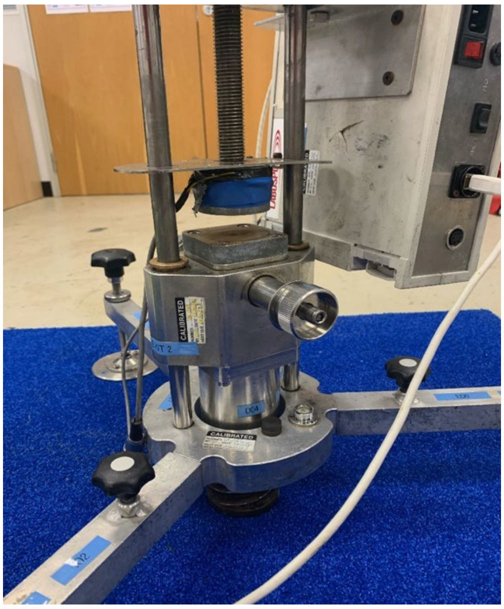

Figure 17. The modified AAA with a reduced drop mass of 10 kg and a reduced drop height of 20 mm

Figure 4 shows an example of a force-time curve from a modified AAA drop onto a global hockey surface. It can be seen that the peak force is 650 N, and the contact time is just over 20 ms. It is evident that the impact loading behaviour of the modified AAA is very similar to 3D skills impact loading as measured on the force plate (section 4.3).

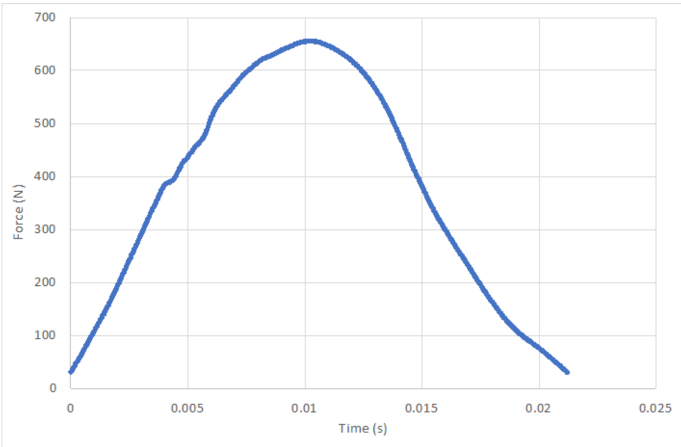

Figure 18. Example Force-Time data output for the modified AAA on global hockey surface

The AAA force data was processed using a 30 N trigger point to determine the start and end of impact (not the standard 200 N trigger point). This lower trigger point has been found to provide a more accurate measurement of surface deformation as per the newly proposed FIFA method.

The characteristics of National and Global hockey systems were evaluated using this dynamic loading test. A new parameter of 3D Surface Stiffness (N/mm) is proposed whereby,

$$3D\ Surface\ Stiffness = \frac{Peak\ Load\ (N)}{Peak\ deformation\ (mm)}$$

Table 6. 3D Surface Stiffness results on National hockey surfaces

Surface	Test	Peak force (N)	Peak Deflection (mm)	3D Surface Stiffness (N/mm)
National A	1	1417	2.1	675.9
	2	1227	1.9	636.7
	3	1420	1.9	759.6
	4	1508	1.9	784.8
	5	1580	2.1	765.5
		1430	2.0	724.5
National B	1	1481	1.6	915.6
	2	1495	1.6	940.2
	3	1594	1.5	1098.3
	4	1481	1.6	942.5
	5	1580	1.6	1007.5
		1526	1.6	980.8

Table 7. 3D Surface Stiffness results on Global hockey surfaces

Surface	Test	Peak force (N)	Peak Deflection (mm)	3D Surface Stiffness (N/mm)
Global A	1	916	3.8	241.7
	2	758	3.4	220.8
	3	785	3.4	230.7
	4	806	3.8	211.8
	5	942	3.5	270.5
		841	3.6	235.1
Global B	1	787	3.4	233.4
	2	952	3.7	256.0
	3	954	3.5	274.2
	4	897	3.3	275.2
	5	971	3.3	292.4
		912	3.4	266.2

It can be seen that the 3D skills impact behaviour of Global hockey surfaces differs from National hockey surfaces in a number of key areas.

- Peak Force is lower on Global hockey surfaces.
- Peak Deflection is higher on Global hockey surfaces.
- 3D Surface Stiffness is lower on global hockey surfaces.

5.4 Stick-surface friction

A test method was developed to measure the coefficient of friction between a hockey stick and the playing surface.

A sledge with three representative hockey stick profiles is pulled at a constant regulated velocity by a large shear tester apparatus. A sensitive load cell measures the frictional forces that are acting on the hockey sledge. The coefficient of friction (CoF) is determined by dividing the average frictional force (horizontal) by the average vertical force (the sledge's weight).

$$CoF = \frac{Frictional\ force}{Vertical\ force}$$

The shear tester apparatus comprises a rigid frame, with a movable carriage that is driven by powerful electric motors. Hockey turf is located under the rigid frame, and the carriage pulls the hockey stick sledge across the turf through a sensitive load cell. The test is conducted at a speed of 2 m/s to mimic the initial phase of an 'injection' (see Figure 8). The hockey stick sledge is pulled across the playing surface at a constant velocity for a minimum of 0.5 metres.

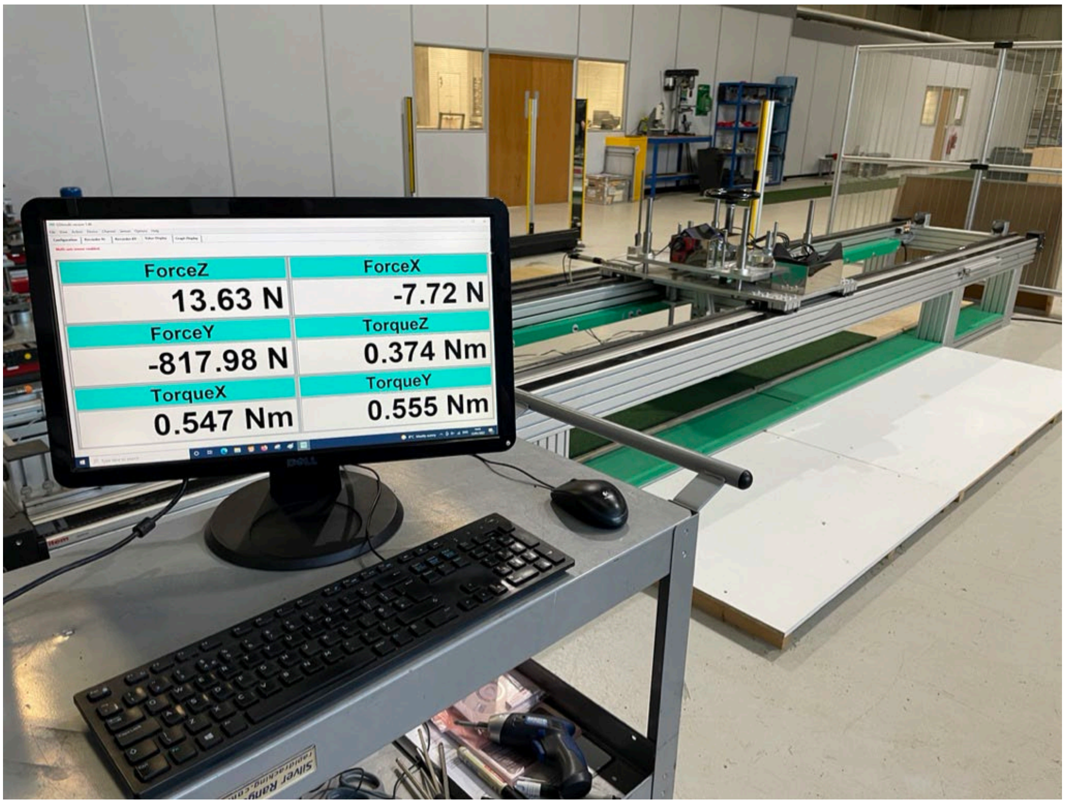

Figure 19. The shear tester apparatus

The hockey stick sledge comprises a of stainless-steel plates (to avoid water corrosion) with three plastic hockey stick profiles mounted beneath. The hockey stick profiles are mounted at an angle of 45 degrees to mimic the stick orientation during an injection. The total mass of the sledge is 14 kg. This weight is representative of the average force that is applied to the surface during an injection (see Table 4).

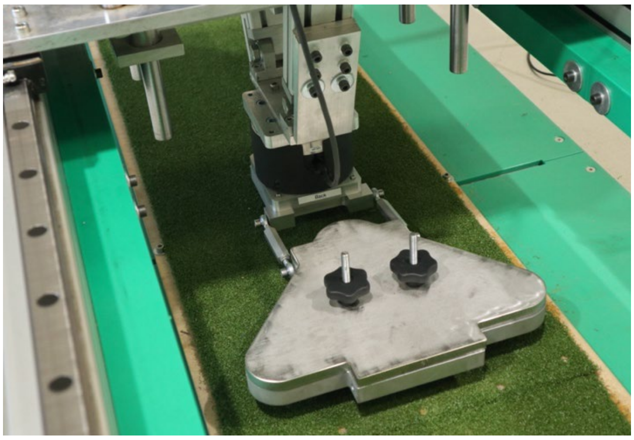

Figure 20. The hockey stick sledge showing the pivoted attachment to the load cell

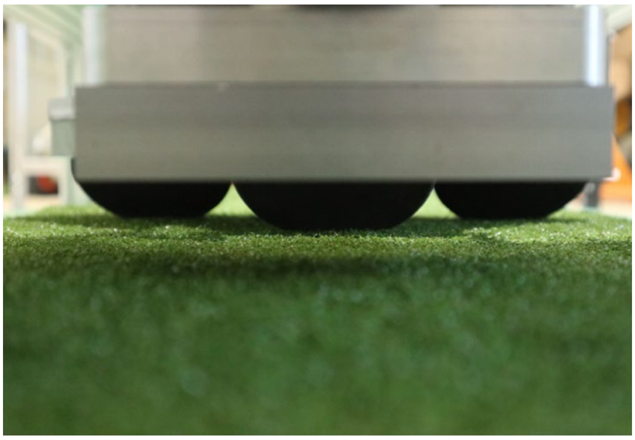

Figure 21. The hockey stick sledge showing the three stick profiles (note the arrangement to avoid overlapping)

Global systems are watered with 1 litre of water per square metre immediately prior to the test. To account for any potential directional effects of the yarn, each carpet is tested with five repeats in one direction, and five repeats in the other direction. The average of all 10 repeats is calculated.

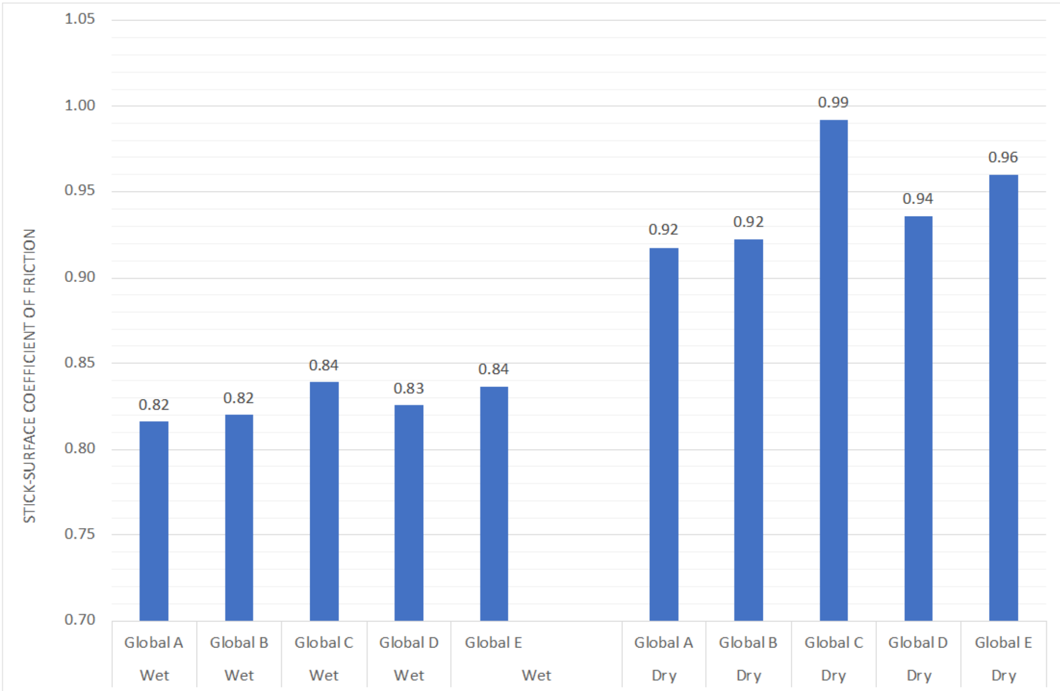

Figure 22. Results from the stick-surface coefficient of friction tests

Five global hockey surfaces were tested for stick-surface coefficient of friction in both a wet condition, and a dry condition. The results show a clear difference in coefficient of friction between the wet and dry conditions.

Stakeholder feedback on the initial stick-surface friction test requested that more realistic hockey stick profiles to be implemented (shape and material). A batch of Mercian CKF90 hockey sticks were sourced from the manufacturer and attempts were made to fix these real hockey stick heads to the friction sledge. Despite significant efforts, this was deemed to an unfeasible approach due to the following issues.

- Cutting the hockey stick heads from the main stick is non-trivial and non-precise.
- Filling the hockey stick head with resin and setting a tread insert is non-trivial and non-precise.
- The internal geometry of the different sticks heads is variable due to aspects of the manual manufacturing process.
- Setting the hockey stick heads at a defined oblique angle to the ground is non-trivial and non-precise.
- Small errors in the alignment of the hockey stick heads were found to create differences in the coefficient of friction results.

With the approval of the FIH, an alternative approach was implemented. A Mercian CK90 hockey stick head was 3D scanned to generate an accurate CAD geometry. This geometry was then modified to introduce a supporting base to allow accurate and secure mounting of the hockey stick profiles to the friction sledge. The hockey stick head profiles were 3D printed in a carbon fibre composite (PA12-CF). This material is widely available and is similar to the materials used in a real hockey stick.

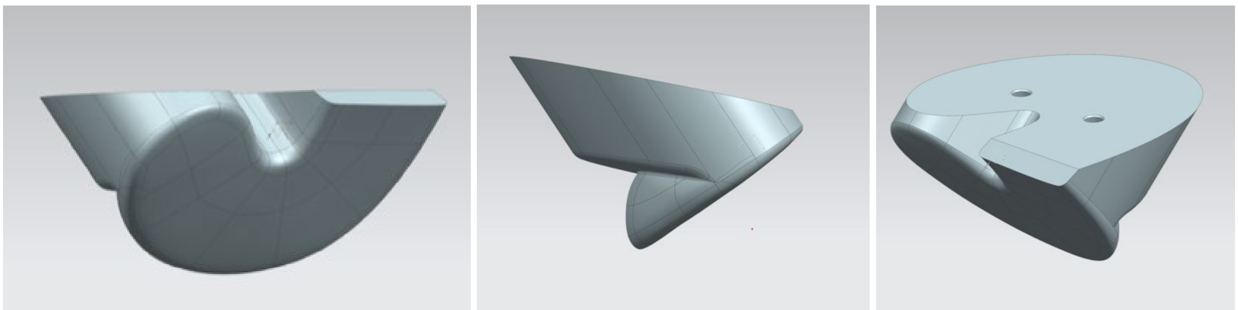

Figure 23. The 3D scanned hockey stick head profile

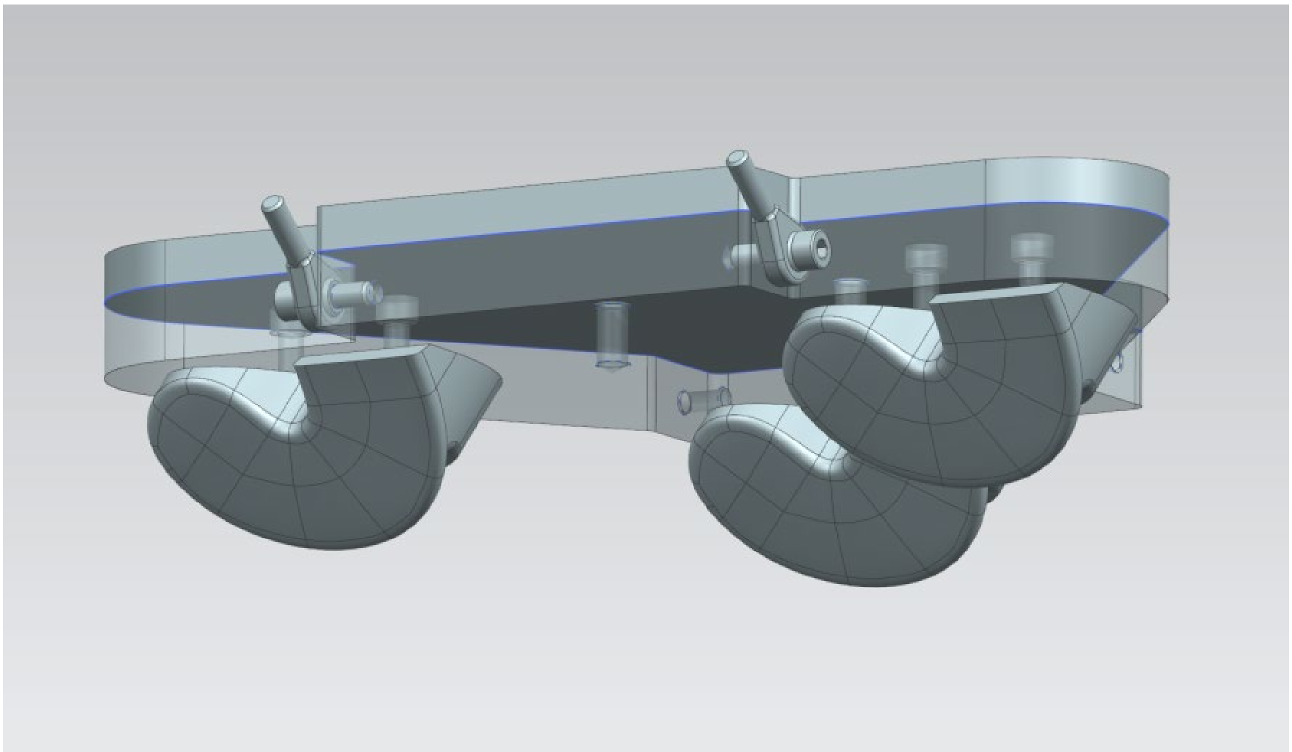

Figure 24. The 3D scanned hockey stick heads attached to the friction sledge

Appendix A – Feedback from stakeholders on the proposed methods

Table 8. A summary of feedback from stakeholders

Topic	Comment/issue/feedback	Identified by whom?	Labosport response
General	Project not meeting brief	Sports Labs	Disagree - the project has been conducted with rigour and each work package was approved by the FIH
General	Ball bobble, heat and foot friction not included in proposed tests	Sports Labs	The player interviews and questionaries did not identify these issues. The project had limited resources and need to focus on the most important parameters
General	Equipment not portable / lab only tests	Sports Labs	The tests are lab based, as approved by FIH
General	Can Labosport test with a lubricated ball	Sport Group	It is possible to test a lubricated ball, but only on the ball surface information tests (not stick surface friction, not 3D skills)
General	Water level – 1 L/m^2 or 31 L/m^2	Sports Labs	Standardise and use 1 L/m^2 as per other FIH tests. Labosport did test with other water levels, and it has a strong influence on the results.
Ball speed test	Why are the light gates 2 metres apart?	ISA KIWA	Apologies, this was a mistake in the initial report. The distance between the light gates should be 1 metre. The ball is travelling fast and if the gates the measurement system struggles to identify a time difference.
Ball speed test	Concerns about the repeatability of launch conditions using a ball cannon	ERCAT | ISA KIWA	Labosport found good repeatability with the ball cannon, but it is important to regulate the initial angle (zero degrees), and the initial height.
Ball speed test	Should the bell be skipping or rolling?	Sports Labs	The ball is observed to skip during match play. Labosport want to measure this skipping behaviour. Ball roll is fundamentally different to ball skipping. During a ball roll, there is no friction.
Ball speed test	Is the speed representative	Sports Labs	The chosen speed is representative of ball speed in hockey. Players can hit the ball with a wide range of speeds, and the chosen speed is within this range. It is a speed that is practice in the lab, and it is a speed that differentiates between surfaces
Oblique bounce test	Are the initial conditions representative?	Sports Labs	Players can launch balls with a range of speeds and angles. The chosen speed and angle is representative of what happens in hockey.
Oblique ball bounce test	Were different shock pads used in the testing?	Sports Labs	A range of different shock pads were used in the testing
Oblique ball bounce test	There is a not a big difference in results between national and global systems	Sports Labs	Labosort disagree - 1.6% difference in pace is significant, measurable, and important for players.

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3D skills test	Why apply 9000N	Sports Labs | ERCAT	Labosport agree that 9000N is a large load. 5000N could be more appropriate.
3D skills test	Is it possible to use a hockey ball profile as the indenter?	Sports Labs | ERCAT	Nice idea and this could be done, however not sure if it would differentiate between products any better than a flat plate
3D skills test	Were different shock pads used in the testing	Sports Labs	A range of different shock pads were used in the testing
3D skills test	Were national systems tested without sand?	Sports Labs	No - the focus was to obtain thresholds on global systems, with a comparison check on national systems to ensure that there was a difference
3D skills test	The proposed test is not dynamic and doesn't represent a player hitting a ball into the surface	Sports Labs | ERCAT	Labosport developed pendulum type test to strike ball into the surface, but this was not successful as the hockey skill is very precise and difficult to perform. The vertical response of the surface is indirectly linked to 3D skills, it is different between national and global systems, and it can be measured accurately.
3D skills test	Is it possible to use the AAA and measure deformation? This might be a good dynamic measurement relevant to 3D skills	ISA KIWA	Labosport agree that this is a good idea. Testing from a low AAA drop height should be undertaken.
Stick-surface friction	How does a sledge mass of 14kg relate to the force plate data	Sports Labs	A plate mass of 14KG relates to 46 N per hockey stick profile. This vertical load is representative of what happens during an injection.
Stick-surface friction	The test only relates to the first 'slow' phase of the injection	Sports Labs	The slow speed phase is at least 80% of the contact time. It is during this time that stick chatter is likely to be experienced.
Stick-surface friction	Can a tensile test bench be used for this test?	Sports Labs | ERCAT	A tensile bench might not create a large enough displacement. However, the proposed test method only describes the movement of a sledge at a controlled velocity, and the measurement of the frictional force.
Stick-surface friction	Do not use 3D printed nylon sticks. Need to use unified realistic sticks that will not wear.	ERCAT | ISA KIWA	Modify test method to use actual sticks that are cut, filled with resin and then mounted to the sledge. Or use a more accurate geometry and more accurate material.

Appendix B – Confidential details of hockey turf systems tested (to be redacted for all non-FIH readers)

Identifier	Manufacturer	Product name	Details
Global A	[redacted]	[redacted]	[redacted]
Global B	[redacted]	[redacted]	[redacted]
Global C	[redacted]	[redacted]	[redacted]
Global D	[redacted]	[redacted]	[redacted]
Global E	[redacted]	[redacted]	[redacted]
[redacted]			
National A	[redacted]	[redacted]	[redacted]
National B	[redacted]	[redacted]	[redacted]
National C	[redacted]	[redacted]	[redacted]
National D	[redacted]	[redacted]	[redacted]
National E	[redacted]	[redacted]	[redacted]

Product details retracted to maintain confidentiality.

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