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The development of a translational traction rig to investigate the mechanisms of traction in 3G turf

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Abstract

During football specific movements a high translational traction is desired at the shoe-surface interface to facilitate player movement. Translational traction is commonly assessed through bespoke mechanical test devices which provide a more repeatable tool for characterising the shoe-surface interaction compared to player testing. Following development, application of the rig is demonstrated through an initial investigation into the effect of the number of studs and stud orientation on translational traction. The translational rig consists of a tray attached to two trails, with surface samples of varying specification placed in the tray. A number of stud configurations were chosen and tested on a 3G artificial turf sample. The initial stiffness response of the surface as well as larger displacements were considered to help inform the mechanisms of traction. The study showed the increasing force as the number of studs increased and how the positions of the studs also relate to the forces produced in the infill and the effect on the mechanism of traction.

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Keywords:

1. Introduction

During football specific movements a high translational traction is desired at the shoe-surface interface to facilitate player movement [5]. Translational traction is commonly assessed through bespoke mechanical test devices which provide a more repeatable tool for characterising the shoe-surface interaction compared to player

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testing. Whilst there are several mechanical test devices available [2,3,4] these tend to be limited by not using experimental measurements captured from player testing to set the boundary conditions, and therefore may not give valid results. This study aimed to develop a translational traction rig designed to improve and draw on features from current mechanical tests. Following development, application of the rig is demonstrated through an initial investigation into the effect of the number of studs and stud configuration on translational traction. A model of the different forces produced by the rig are shown in Figure 1. These include the normal force (1), a force from the stud plate (2), a force from the studs (3), and the friction from the rails (4). By changing the stud number and configuration, the contribution to the total force of each component can be seen.

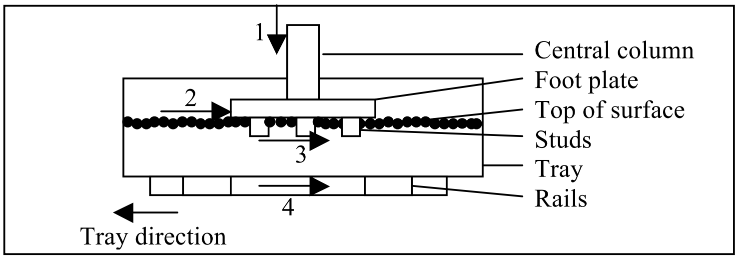

Fig. 1. Components of force during use of translational rig.

2. Method

2.1. Development of rig

The translational traction rig consists of a tray attached to two rails allowing for near frictionless horizontal movement. Surface samples of varying specification can be placed in the tray and are easily inter-changeable. A metal foot with studs screwed in underneath can be placed on the surface and weights added on top to replicate the normal load applied by the player to the surface. Attached to a vertical column, the foot and weights are free to move vertically during normal operation thereby ensuring a constant normal load. Foot orientation (relative to the direction of tray movement) can be altered in 10° increments thereby allowing a range of foot plant angles to be investigated. The tray is attached to an Instron 3365 uni-axial tensile machine which applies a horizontal force, pulling the tray along the rails. The Instron can be force (up to 5kN) or displacement/velocity (up to 0.0167 $m \cdot s^{-1}$) controlled with the latter being used in this study. A vertical displacement sensor is attached to the foot section allowing stud penetration into the surface to be quantified throughout the translational movement.

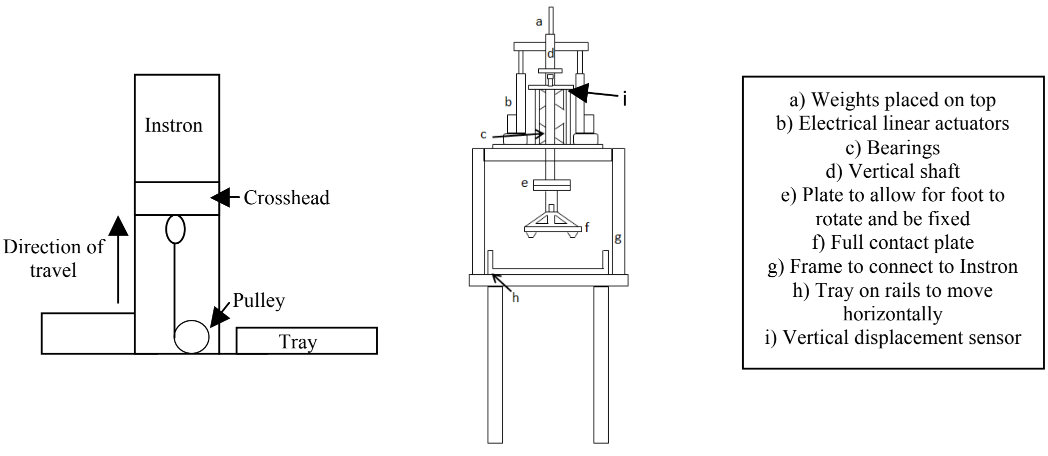

Fig. 2. Schematic of translational traction rig. Left: Side view, Right: Front view

2.2. Testing protocol

Initial testing of the rig was required to troubleshoot operational issues. This included synchronising the vertical displacement sensor with the horizontal force and displacement data; setting the datum level for the vertical displacement sensor; and analysing player data (collected in an earlier study) to inform the test boundary conditions (normal forces, horizontal displacements/velocities). Once the operational issues were resolved, an initial study was conducted to investigate the effect of the number of studs and stud orientation on translational traction.

A 120 mm^2 aluminium square plate with 9 stud holes (3 x 3), 45 mm apart was attached to the central column in place of the foot shaped plate, to be able to investigate an increase in the number of studs at a fixed distance apart. A distance of 45 mm between studs was chosen as this is the same distance between studs on the rotational traction device so results may be compared. The studs used were 13 mm football studs with dimensions shown in Figure 3. A number of stud position configurations were used. Codes of A-G were assigned for future reference. These are also shown in Figure 3. The front (F) and back (B) of the plate are shown.

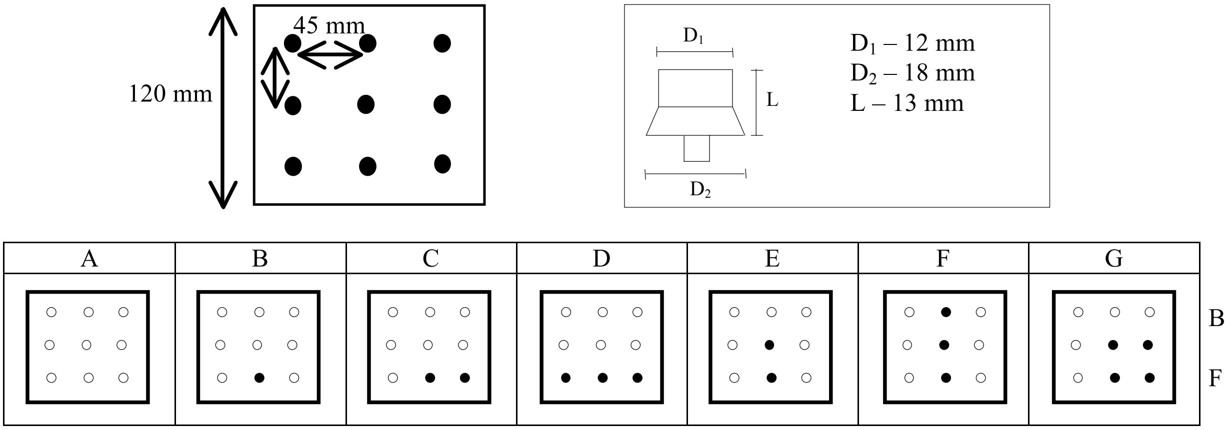

Fig. 3. Stud plate (Top left), stud dimensions (Top right) and stud configurations A-G (Bottom) with filled circles showing the placement of the studs. F = front of plate, B = back of plate.

For each test, the Instron was programmed to pull the plate 80 mm along the surface, stop for a second and then increase in speed for one second. This point would then act as a marker for the synchronising of the vertical displacement sensor. A normal force of 45 kg (35 kg on top of the rig and the weight of the central column) was placed on the plate. This was the same mass as the rotational traction device. The testing was completed on a 3rd generation multi-purpose long-pile artificial turf, measuring 500 mm^2 to fit in the tray, sourced from a recent new-build facility at Loughborough University. The tray was designed with allowance for edge effect when using a foot plate of length 285 mm, moving for a distance of 100 mm. A 25 mm rubber shockpad was used, with 60 mm monofilament polyethylene fibres, 15 kg/m^2 of sand and 15 kg/m^2 rubber crumb. The surface was rolled 200 times prior to testing to simulate a used surface. It was then raked between trials and infill height was measured between trials to ensure a similar height was maintained throughout testing. The Instron pulled the tray at 0.0167 $m \cdot s^{-1}$, the maximum velocity possible.

2.3. Analysis

The Instron outputs Force (N) against Extension (mm), where extension is the distance the tray moves, which allows for further analysis. Based on player data [1] and previous mechanical testing [6], the focus is on the initial stiffness response of the surface over 5 – 10 mm of movement, but also considering larger displacements which may help to inform the mechanism of traction. Two gradients were calculated, the initial steeper region (X) followed by the second gentler gradient (Y). The start of movement was defined as when the force first exceeded 0.1 N. Figure 4 shows a typical graph with the two gradients highlighted.

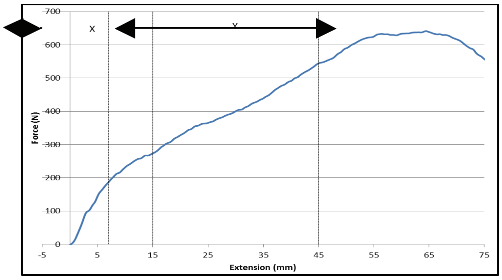

Fig. 4. Graph showing the two calculated gradients. X = from the start of movement to where visually, the gradient began to decrease; Y = between 15 and 45 mm where the gradient was consistent.

The vertical displacement sensor output displacement and time from LabView into Microsoft Excel for further analysis. This data could be matched up to the force data collected from the Instron. As mentioned in 2.2, at the end of the tray movement, the Instron was programmed to increase in speed for a second to provide a marker for synchronising the data. These points could then be matched to work out the point that the tray started to move. The top of the surface was measured using a calibration platform. The platform was placed on the surface, ensuring it was level using a spirit level. The distance between the top of the platform and the bottom of the stud plate was measured. The height of the platform and stud length was taken into account to calculate the top of the surface (top of the infill). Two values were calculated; the first being the distance that the studs moved into the surface as the actuators moved the stud plate and the mass down. The second value is the maximum distance that the studs moved into the surface as the tray moves.

3. Results

Figure 5 shows a typical trial for each stud configuration. It highlights the difference in forces produced and patterns developed depending on the number of studs and stud placement. This will be discussed further.

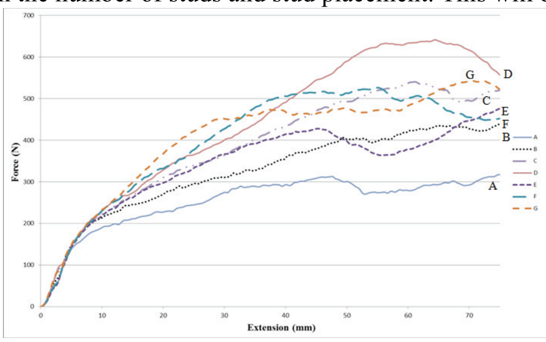

Fig. 5. A typical trial for each stud configuration.

Table 1 shows a summary of gradients X and Y for each stud combination. These are an average from three trials. The standard deviations show the variation in the three trials for both gradients.

Table 1. X and Y average gradients for each stud configuration with standard deviations (SD).

	Stud configuration						
	A	B	C	D	E	F	G
Gradient X (N/mm)	28.52	29.23	30.85	29.25	28.33	29.71	31.82
SD	1.44	0.89	1.35	0.86	0.77	0.83	0.87
Gradient Y (N/mm)	4.54	4.68	6.95	9.42	6.20	9.38	13.39
SD	1.44	0.45	0.45	1.35	0.97	0.79	0.57

Table 2 shows the results collected from the vertical displacement sensor. It displays the distance that the studs moved into the surface as the actuators moved the stud plate and the mass down. It also shows the maximum distance that the studs move into the surface as the tray moves.

Table 2. Vertical displacements of studs into the surface. 0 = top of surface. > 0 = below top of the surface.

	Stud configuration						
	A	B	C	D	E	F	G
Vertical displacement of studs/stud plate into surface as stud plate and mass is placed onto surface (mm)	1.60	14.45	14.07	13.70	13.87	13.90	14.29
Maximum vertical displacement as tray moves (mm)	1.55	0.53	0.55	0.50	0.64	0.45	0.49

4. Discussion

The translational traction rig was designed and built before initial troubleshooting. Testing was completed with a study looking at the number of studs and stud configuration. The two gradients (X and Y) were compared within stud configurations and general trends discussed. Figure 5 was analysed to identify where the different forces (shown in Figure 1) contribute to the total force measured.

It is hypothesised that as the studs move vertically into the surface, the infill is compressed and may provide a zone of stiffer infill around the studs. Along with the fibres providing reinforcement, this contributes to the initial higher resistance [6]. Therefore it may be expected that the resistance would increase with the number of studs. Forces 1 and 4 (Figure 1) stay consistent throughout testing due to the normal force remaining at 450 N.

The results with no studs attached to the stud plate (A) show that there is still a resistance produced by the plate. Figure 5 (A) shows an initial higher stiffness of 28.52 N/mm before the gradient reduces at ~ 8 mm and increases to a peak of 310 N at ~ 45 mm before reducing at 50 mm then increasing further. It is hypothesised that the resistance exists due to the plate moving through and dispersing the infill. The results in table 2 show that the plate has penetrated into the surface by 3 mm which reinforces that the plate would be pushing through the infill. These results show the contribution of forces 1, 2 and 4, with the following showing the increasing contribution of force 3.

With the addition of one stud (B), the initial gradient increases (Table 1). This is due to the stud compressing the infill around the stud as the plate moved vertically into the surface. The stud then moves horizontally through this stiffer region of infill as the tray moves, resulting in the high resistance. After ~ 8-9 mm, a consistently higher force of ~ 50 N between 15 – 40 mm is produced compared to no studs; however the force continues to increase to 440 N, unlike the results with no studs which reduces in force. With the stud being singular, there are no studs situated behind which reach the path of the preceding stud, which would cause the resistance to reduce. The resistance is building up as the infill is compressed and the fibres are resisting infill displacement and shearing. Table 2 shows the vertical stud displacements. As the stud plate is placed on the surface, it penetrates the surface by 14.45 mm. This shows that the studs are fully penetrating the surface (13 mm) and the stud plate is also penetrating the infill by 1.45 mm. Although minor, the vertical penetration with one stud was largest. It is hypothesised that this is due to a smaller surface area, compared to an increased number of studs. As the tray moves, the results show that the plate moves a further 0.53 mm into the infill.

Stud configurations C and E were with two studs attached to the stud plate, in different positions (Figure 3). As hypothesised, the force produced with two studs is higher compared to one. Table 1 shows that gradient X was higher for configuration C compared to E. Gradient Y is seen to be similar for C and E, which shows, between ~ 8 and 35 mm of the movement, the stud position has no effect on the force being produced. For E, this is until a peak is reached at ~ 45 mm and the force reduces to 360 N before increasing again to ~ 470 N. This decrease in force may be due to the stud behind reaching the path of the preceding stud. Configuration C follows a similar pattern to B (one stud), with the continued increase in force up to ~ 540 N, although it does begin to decrease around 60 mm. In contrast to E, this may be due to there being no studs behind and reaching the path of a preceding stud.

Similarly to two studs, three studs were tested in two orientations (F and D). For F, a peak is reached at ~ 55 mm with 520 N before reducing to 450 N at 75 mm. Again, the reduction in force is hypothesised to be due to the studs being directly behind one another; therefore they reach the path of the stud in front, where the infill has been cleared. Unlike E (with two studs), the force does not increase again which may be due to the extra stud, causing more of the infill to be dispersed. Gradient Y is similar for both F and D. This reinforces the earlier observation of the stud configuration having no effect on the force being produced between ~ 8 and 35 mm. Figure 5 shows that with D, the force continues to increase gradually until ~ 60 mm at 630 N where it reduces. This may be due to the infill/fibre zone in front of the studs failing. As hypothesised, the force reached is higher with the extra stud, and with this combination (D), due to the having no preceding studs.

The final stud configuration (G) tested was with four studs (2 x 2). The initial gradient X gave the highest value of 31.82 N/mm. This was hypothesised due to the four studs causing a higher resistance with the increased amount of compressed infill being pushed through. Gradient Y is highest of all combinations due to the increased number of studs. The trial in Figure 5 shows an increase in force until 30 mm where it flattens out for 25 mm, before it increases again. This flattening in force may be due to the studs behind reaching the path of the preceding studs. Table 2 shows the similarity of vertical stud displacement of the studs and stud plate (C – G), both when the stud plate is placed on the surface and when the tray moves. This increase in studs shows the effect that force 3 (Figure 1) has on the contribution to the total force, with this being the single variable changing.

Severn (2011), found similar results to this study when using two different test devices. They saw an initial region of increasing resistance followed by a more gradual increase. Furthermore, they observed with their second device, a peak in resistance followed by a reduction, which was also observed in several trials in this paper (Figure 5). This device had a similar vertical load of 44 kg and reached a peak of 600 N.

5. Conclusion

The translational traction rig developed has been demonstrated to be a useful device both for the basic measurement of traction as well as a research tool to further our understanding of how traction is utilised by players on artificial turf.

The results and discussion have aimed to show how the various components contribute to the total force (Figure 1). Figure 5 show the forces produced with the contribution of the stud plate and as expected, the increasing force with the additional number of studs. The gradients, X and Y also highlight the increase in force with an increase in the number of studs. It is clear the positions of the studs also relate to the forces produced in the infill and has an effect on the mechanisms of traction.

Further studies are planned to investigate additional variables related to traction both surface related e.g. initial state of the infill, infill size and pile density, and footwear related, e.g. stud design and stud configuration.

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