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A study on the influence of the change of football artificial turf's particle filling density on sports biomechanics characteristics

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Abstract. In order to research the influence of the change of football artificial turf's particle filling density on sports biomechanics characteristics, the density of rubber particle filled in artificial turf is changed and its influences on traction on the interaction surface of football shoes and artificial turf are also explored. Tests on kinesiology of the player's 45 degree side cut and linear start and dynamics are carried out to discover the changes of biomechanical characteristics on the condition of different tractive forces, find out the influence on the sports performance and injury of players when the interaction surface traction of shoes and artificial turf are changed and meanwhile provide theory support and experimental basis for the standard making and instrument developing of artificial turf.

Key words. Artificial turf, sports performance, biomechanics, traction.

1. Introduction

The traction on the interaction surface made by shoes and the field is the key factor affecting action forms and performance of players, which support players the starting, braking and steering. Interaction surface of low traction may lead to "slipping" under the feet of players and feet may be "fixed" on the field if the traction is too high [1]. It turns out that the interaction surface traction is an important feature after shoes comfort through an investigation on football shoes. It is more critical than stability, traction, weight of shoes and the speed and accuracy of football playing. The type, fiber length, density, and type, size, depth and density of fillings as well as different humidity around may give rise to changes of the traction's effect [2]. But at present, when evaluating on changed interaction surfaces caused by different types of shoes, there are more studies about functions of the traction rather than the change of field surface.

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2. Literature review

Playing football is a sport involving body moving. It is found that injuries occurring in football are more common than other sports. Main injures are contusion, sprain and strain, and the main injuring positions are knee and ankle joints and muscle in ligament of the thigh and lower leg [3]. Combining former literature, Inklaar figures out that 60 % to 90 % injuries occur in the lower limbs and discovers that some internal factors such as age, old injuries and external factors including lacking of training, low training or race rate and field environment can contribute to injury decrease [4]. Studies about injuries caused by football playing focus on the low limbs and some on cranial part. The injuries result from direct hit and upward impact force after on the ground. Theobald et al. [5] test on cushioning property of the third generation artificial turf and defined the standard of head impact to evaluate the performance of moving surface and further offer proper suggestions for decreasing the rate of mild head injury.

45 degree cut side movement is chosen in the study. In that direction change is the common basic movement form in football, and meanwhile, the abrupt direction change in rapid movement will give rise to much load to the legs and will injury ligament structure easily.

On the other hand, the acceleration ability to start from static state can reflect the basic quality of football player which is related with the traction in the interaction interface made by shoes and the field.

3. Methods

3.1. Object

26 male football players from Hainan Tropical Ocean University, with the second exercise level or over and the size of 42 (EUR) were chosen as experimental objects. Before the experiment, they have not strenuous exercise 48 hours before the experiment and there has been no obvious injury in the past a half year and dominant foot of them are the right foot. They are 24.3±1.4 years old with the height of 174.9±3.2 cm, the weight of 70±7.1 kg and training period of 10.4±3.5 years.

3.2. Research data

Experimental shoes are from foreign sports brand with the size of 42 (EUR) and the weight of 0.24 kg. Spikes of the shoes are short plastic spikes with the length of 0.5 to 1 cm which is suitable for players to train and race. The experimental artificial turf is manufactured by special manufactures in China, and the turf meets national standard regulated in Artificial Grass for Sports [6]. Fiber height of grass is 50 mm and the area of turf is the same as the ergograph with the length of 60 cm and width of 40 cm. Fillings of the turf are rubber particles with the size of 0.5 to 2 mm.

During the experiment, the weight of rubber filling particles are 0 kg, 0.5 kg and 1.5 kg. These particles are paved evenly and compacted tightly to create artificial turf with different densities, which are named Field E, Field H and Field F. Density of Field E is 0 kg in that the non-density field is often chosen to make turf experiment in lab in China and the rest of other countries in the world. Even if there is no clear limitation in the density of real artificial turf, the paving of rubber particles is carried out in 5–8 $\mathrm{kg/m^2}$ referring to advice from manufactures. Thus particles of 0.5 kg and 1.5 kg are chosen to simulate two fields which are within and lower than the above density.

3.3. Data collection and processing

3.3.1. Traction test. The field temperature is 23.3 °C and the humidity is 46.7 % on the experiment day. The artificial turf is put in the environment for over three hours before the experiment. In preparing the experiment, a unfilled artificial turf is pasted on the ground son that there is no slipping between ground and the turf. A shoe last with the size of 42 (EUR) is put in a shoe and later it is fixed on the traction tester. The shoe is parallel with the long side. the shoe and other attachment devices like shoe last weigh 4.748 kg. 30 kg weight is added in the vertical direction. Through the electrode, traction tester drags the shoe at uniform speed of 0.3 m/s. Relatively stable traction values in the process of dragging are recorded and indicated through the sensor. The dragging is repeated for 5 times. The shoe is adjusted to be parallel with the short side of the turf, and the above test is repeated for 5 times. After the test on the traction of non-filling artificial turf is completed, rubber particles with the weight of 0.5 kg are paved in the turf. After they have been impacted tightly, the above experiment process is to be repeated 5 times in terms of vertical and horizontal traction and reaction vales are recorded. At last particles of kg are filled in the turf. Traction test are done after they are impacted. As what have been done before, the experiment process is repeated 5 time and the vertical and horizontal traction values are recorded [7]. The average value and standard deviation of 10 traction values with both vertical and horizontal tests are counted on the condition of same filling density so as to define the traction of shoes and the artificial surface on the condition of different densities.

3.3.2. Kinematic and dynamics tests. 45 degree side cut requires that the object should stats approaching 6 to 8 m from the force measuring platform at the speed of 4±0.3 m/s. The experiment players make side cut moving 45 degree inclined to the left on measuring force platform of the artificial turf with the support of right leg. 3 minutes later they can stop running. At the regulated speed, the objects make no other change in steps and at the same tine, only when their right feet step on the measuring force platform fixed with artificial turf can an effective an effective test be finished.

Linear starting requires that people involved in the experiment should step their both feet on two measuring platforms. They make speed-accelerated start in the standing posture they are familiar to. 3 minutes later they can stop running. Only when both feet of them are on two measuring platforms, the measurement is effective and the test can be finished.

In the real test, the objects are required to make 45 degree cut side and linear start in the non-filling artificial turf at first. Later they repeated the moving on two artificial turfs with particles of 0.5 kg. They are required to repeated again the moving on the artificial turfs with particles of 1 kg based on the turf of 0.5 kg. In the process, every object should make 3 times of test in terms of each moving.

3.3.3. Data processing. 3D coordinates of marking points in the experiment are smoothed through Butterworth low passing filter method with the truncation frequency of 10 Hz.

(1) Calculating the low limbs center

The center of knee joint, external knee center, center of ankle joint and external center as well as hip center are calculated though Bell's [8] research.

Local coordinate system of right hip joint (R.Hip.JC) is HR. The origin is the right and right anterior superior iliac spine point (Mid.ASIS), X, Y and Z standing for i_{HR},j_{HR} and k_{HR}:

$$j_{\mathrm{HR}} = \frac{\mathrm{R.ASIS} - \mathrm{Mid.ASIS}}{|\mathrm{R.ASIS} - \mathrm{Mid.ASIS}|},\ k_{\mathrm{HR}} = \frac{(\mathrm{V.Sacral} - \mathrm{Mid.ASIS}) \times j_{\mathrm{HR}}}{|\mathrm{V.Sacral} - \mathrm{Mid.ASIS}| \times j_{\mathrm{HR}}},$$

$$i_{\mathrm{HR}} = j_{\mathrm{HR}} \times k_{\mathrm{HR}}\,. \tag{1}$$

(2) Establishing local coordinate of lower limb

In the coordinate system of right thigh, the origin is right hip joint (R.Hip.JC), and unit vectors of each axis are

$$k_{\mathrm{R.Thigh}} = \frac{\mathrm{R.Knee.JC} - \mathrm{R.Hip.JC}}{|\mathrm{R.Knee.JC} - \mathrm{R.Hip.JC}|},\ j_{\mathrm{R.Thigh}} = \frac{(\mathrm{R.Knee} - \mathrm{R.Hip.JC}) \times k_{\mathrm{R.Thigh}}}{|\mathrm{R.Knee} - \mathrm{R.Hip.JC}| \times \mathrm{k}_{\mathrm{R.Thigh}}},$$

$$i_{\mathrm{R.Thigh}} = j_{\mathrm{R.Thigh}} \times k_{\mathrm{R.Thigh}}\,. \tag{2}$$

In the coordinate system of right foot (R.Foot), the origin is right ankle joint (R.Ankle.JC), and unit vectors of each axis are

$$k_{\mathrm{R.Foot}} = \frac{\mathrm{R.Toe.JC} - \mathrm{R.Ankle.JC}}{|\mathrm{R.Toe.JC} - \mathrm{R.Ankle.JC}|},\ j_{\mathrm{R.Foot}} = \frac{(\mathrm{R.Ankle} - \mathrm{R.Ankle.JC}) \times k_{\mathrm{R.Foot}}}{|\mathrm{R.Ankle} - \mathrm{R.Ankle.JC}| \times k_{\mathrm{R.Foot}}},$$

$$i_{\mathrm{R.Foot}} = j_{\mathrm{R.Foot}} \times k_{\mathrm{R.Foot}}\,. \tag{3}$$

In the coordinate system of right foot (R.Foot), the origin is right ankle joint (R.Ankle.JC), and unit vectors of each axis are

$$k_{\mathrm{R.Foot}} = \frac{\mathrm{R.Toe.JC} - \mathrm{R.Ankle.JC}}{|\mathrm{R.Toe.JC} - \mathrm{R.Ankle.JC}|},\ j_{\mathrm{R.Foot}} = \frac{(\mathrm{R.Ankle} - \mathrm{R.Ankle.JC}) \times k_{\mathrm{R.Foot}}}{|\mathrm{R.Ankle} - \mathrm{R.Ankle.JC}| \times k_{\mathrm{R.Foot}}},$$

$$i_{\mathrm{R.Foot}} = j_{\mathrm{R.Foot}} \times k_{\mathrm{R.Foot}}\,. \tag{4}$$

(3) Lower limb joint angle

Joint angle is cardan angle between two neighboring local coordinate systems, which is the movement of distal link relative to proximal link. Namely, R.Foot relative to R.Shank stands for ankle joint movement and R.Shank relative to R.Thigh stands for knee joint angular movement to rotate around X, Y and Z to get the flexion angle, adduction and inclination angle, and medial rotation and lateral rotation angle.

(4) Calculating body barycenter

Revised inertial parameters of human body of DeLeva is adopted to calculate body barycenter by combing striking point scheme of Helen Hayes. Smoothing works are not done in the light of ground reaction. Three-dimensional moment of knee and ankle joint are got through calculation in the use of inverse dynamics, and the ground reaction is standardized to multiples of body weight and moment is standardized to the multiples of height multiplying weight.

3.4. Data processing

Comparison is made through one-way repeated measures ANOVA and the subsequent pairwise comparison is made through LSD method. The first level of deviation probability less than 0.05 means significant level. All data are dealt with by SPSS 17.0 software.

4. Results

4.1. Results of traction test

Interaction surface traction values of the shoe and turf on the condition of three different filling densities are of significant difference (Table 1, $p < 0.01$) and subsequent pairwise comparisons are all of significance ($p < 0.001$). Thus, three interaction surfaces Field e, Field h and Field f are turfs of low, medium and high traction turf.

Table 1. About the turf with three different densities and traction values ($n = 10$)

Turf	Field e	Field h	Field f
Qualitative	Low traction	Medium traction	High traction
Weight of filling particle (kg)	0	0.5	1.5
Traction (N)	233.68±16.71	347.79±5.4	414.03±33.8

a: Compared with Field e, there is of significant difference; b: compared with Field h, there is of significant difference.

4.2. Results of kinematic and dynamic tests

4.2.1. Results of kinematic parameters in the process of 45 degree side cut retardation. Different tractions have no significant effect on the maximum of knee flexion ($p = 0.649$), knee flexion range ($p = 0.508$), maximum of knee adduction ($p = 0.720$), flex angle of ankle joint touching the ground ($p = 0.269$), maximum of ankle joint enstrophe ($p = 0.345$), enstrophe range of ankle joint ($p = 0.81$) and maximum of external rotation ($p = 0.154$). The results are given in Table 2.

Table 2. The influence of different tractions on the lower limbs parameters (unit: $^\circ$, $n = 13$)

Lower limbs joint angle parameters	Turf with low traction	Turf with medium traction	Turf with high traction
Maximum of knee flexion	53.89±8.11	54.23±7.34	53.16±8.56
Knee flexion range	19.51±7.55	20.12±9.31	20.50±8.11
Maximum of knee adduction	3.01±1.54	3.05±1.42	2.94±1.45
Knee internal rotation range	14.93±7.19	13.99±8.29	13.87±6.62
Flex angle of ankle joint touching the ground	20.31±5.88	20.31±7.15	19.36±7.65
Maximum of ankle joint enstrophe	11.76±2.74	11.68±1.83	11.24±1.65
Enstrophe range of ankle joint	5.58±2.29	5.43±2.02	5.75±1.93
Maximum of external rotation	21.55±6.02	20.31±5.24	21.11±5.23

Different tractions have significant effect on gravity acceleration in the process of braking ($p < 0.001$). The effect of high traction on gravity braking (–7.05 m/±2.56 m/) is higher than that of the low traction (–6.01,m/±1.77 m/, $p = 0.003$) and medium traction (–5.88 m/±1.79 m/, $p = 0.001$) and the difference is significant.

4.2.2. Results of kinetic parameter in the process of 45 degree side cut retardation. (1) Results of peak value of horizontal and component of ground reaction force

By comparing the peak torque of ground reaction force in side cut retardation in turfs with different traction (Fig. 1), it is clear that different traction turfs can significantly affect the horizontal resultant peak ($p = 0.004$). After checking, it can be found that the difference of turf with high traction is obvious that that of turf with medium and low traction ($p = 0.001$); turf with different traction can significantly affect the vertical peak of ground reaction force ($p = 0.05$). And the vertical ground reaction through side cut movement in turf with high traction is larger than that of turf with medium traction. Compared with turf with low traction, there is no obvious difference of turf with high ($p = 0.269$) and medium ($p = 0.161$) traction in term of peak value of vertical reaction force.

Table 2. The influence of different tractions on the lower limbs parameters (unit: °, $n = 13$)

Kinetic parameters	Turf with low traction	Turf with medium traction	Turf with high traction
Peak value of horizontal component of ground reaction force (BW)	1.11±0.35	1.13±0.34	1.25±0.43
Peak value of vertical component of ground reaction force (BW)	2.62±0.91	2.41±0.95	2.77±1.05
Loading horizontal component of reaction rate of ground force (BW/s)	41.96±20.12	49.13±21.77	53.14±26.49
Loading rate of vertical component of ground reaction force (BW/s)	99.99±71.38	87.75±56.86	119.25±78.51
Peak torque of knee extension (BWBH)	-0.185±0.048	-0.194±0.043	-0.204±0.037
Peak torque of knee adduction (BWBH)	0.067±0.048	0.075±0.048	0.094±0.043
Peak torque of knee external rotation (BWBH)	0.015±0.004	0.016±0.005	0.018±0.002
Peak torque of ankle flexion (BWBH)	0.153±0.020	0.163±0.017	0.165±0.018
Peak torque of ankle ectropion (BWBH)	-0.054±0.021	-0.055±0.023	-0.059±0.021
hline Peak torque of ankle external rotation (BWBH)	0.017±0.012	0.021±0.009	0.023±0.005

(2) Results of loading rate of horizontal and vertical ground reaction force

By comparing the loading rate of horizontal and vertical ground reaction force in side cut retardation in turfs with different traction (Fig. 2), it is clear that dif-

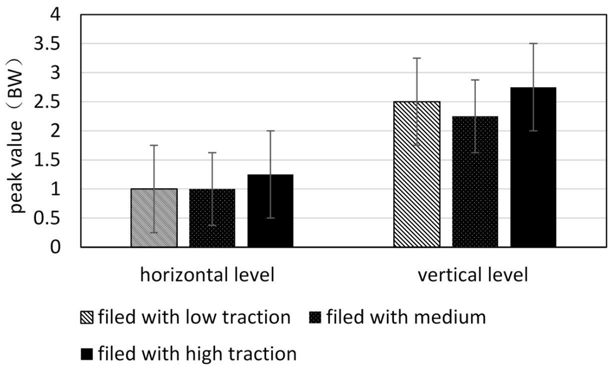

Fig. 1. Comparison of the peak torque of ground reaction force in side cut retardation in turfs with different traction

ferent traction turfs can significantly affect the horizontal resultant loading rate ($p = 0.001$). After checking, it can be found that the difference of turf with low traction is less obvious that that of turf with medium ($p = 0.011$) and high traction ($p = 0.001$); turf with different traction can significantly affect the vertical loading rate of ground reaction force ($p = 0.01$) and the difference of turf with high traction is obvious than that with medium traction ($p = 0.004$).

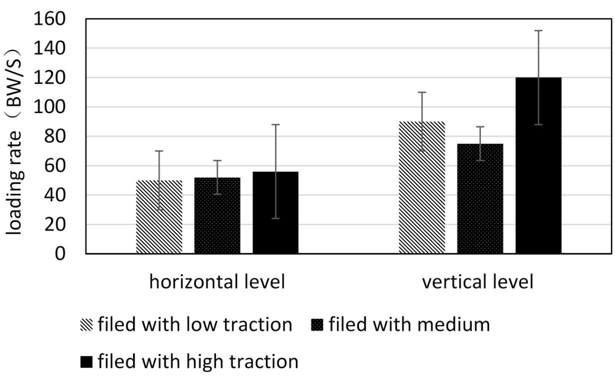

Fig. 2. Comparison of the loading rate of horizontal and vertical ground reaction force in side cut retardation in turfs with different traction

(3) Results of lower limbs three-dimensional peak torque

By comparing peak torque of knee joint in side cut retardation in turfs with different traction (Fig. 3), it can be found that knee extension peak torque in turf with high traction ($p = 0.004$) is obviously higher than that in the low turf ($p = 0.004$). Knee adduction force peak torque in field with high traction is obviously higher than that of field with medium ($p = 0.008$) and low traction ($p = 0.001$). And fields with different fraction have no significant effect on keen external rotation peak torque ($p = 0.624$).

By comparing peak torque of ankle joint in side cut retardation in turfs with different traction (Fig. 4), it can be found that knee flexion peak torque in turf with low ($p = 0.001$) traction is obviously lower than that in the medium turf ($p = 0.0.001$) and high turf ($p = 0.001$). And fields with different traction have no significant effect on knee ectropion ($p = 0.226$) and external rotation ($p = 0.131$) peak torque ($p = 0.624$).

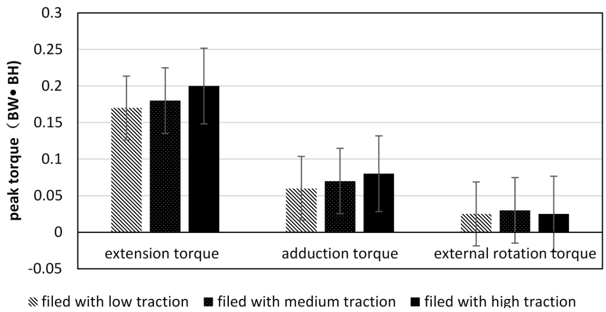

Fig. 3. Comparison of peak torque of knee joint in side cut retardation in turfs with different traction

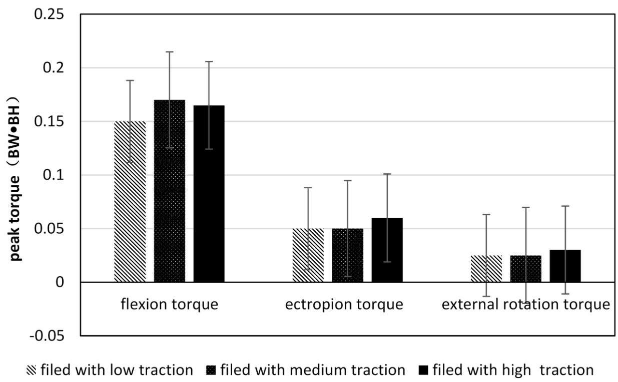

Fig. 4. Comparison of peak torque of ankle joint in side cut retardation in turfs with different traction

4.2.3. Results of biomechanical peak time parameters of ground reaction force in 45 degree side cut retardation. Related kinematics and dynamics parameters of the first peak value of ground reaction in turfs with different densities of shoe-turf interaction surface in 45 degree side cut movement are shown in Fig. 4. In the time, different tractions have significantly effect on vertical ground reaction ($p = 0.013$). After checking, it can be fund that the difference of turf with low traction and high traction is obviously higher than that with medium traction ($p = 0.024$, $p = 0.006$). Different tractions have significantly effect on horizontal background ground reaction ($p = 0.001$). After checking, it can be fund that the difference of turf with low traction is obviously than that with and high and medium traction ($p = 0.004$, $p < 0.001$) and the the difference of turf with medium traction is obviously lower than that with high traction ($p = 0.002$). Different tractions have significantly effect on knee extension torque ($p = 0.007$). After checking, it can be found that knee extension torque on turf with medium traction and high traction is obviously higher than that with low traction ($p = 0.007,\ p = 0.03$) and there is no significant difference in turf with medium and high tractions ($p = 0.51$). Different tractions have significantly effect on knee adduction torque ($p = 0.02$). After checking, it can be found that the adduction torque on turf with medium traction and high traction is obviously lower than that with low traction ($p = 0.023,\ p = 0.005$) and there is no significant difference in turf with medium and high tractions ($p = 0.51$). Different tractions have a significant effect on knee adduction and abduction angle ($p = 0.004$). After checking, it can be found that the abduction angle of turf with low traction is obviously lager than that with medium and high tractions ($p = 0.005,\ p = 0.001$) and the abduction with medium traction is obviously larger than that with high fraction ($p = 0.015$). In the peak time, it can be found from other related parameters that different traction have no obvious effect on knee internal and external rotations ($p = 0.015$), knee extension angle ($p = 0.675$) and internal and external angles ($p = 0.274$).

Table 4. Biomechanical index of peak time of ground reaction force in turf with different interaction surfaces ($n = 13$)

Parameter	Turf with low traction	Turf with medium traction	Turf with high traction
Vertical ground reaction force (BW)	2.87±1.0	2.54±1.05	2.97±1.1
Horizontal background ground reaction (BW)	0.49±0.28	0.64±0.3	0.77±0.2
Knee extension torque (BWBH)	0.024±0.096	-0.021±0.08	-0.013±0.06
Knee adduction torque (BWBH)	0.074±0.049	0.047±0.04	0.049±0.04
Knee internal and external rotation torques (BWBH)	-0.001±0.006	-0.0002±0.007	-0.0003±0.008
Knee extension angle (ş)	37.88±6.06	37.99±5.24	37.13±7.19
Knee adduction and abduction angles (ş)	-1.11±3.01	-0.75±2.7	-0.52±2.9
Knee external rotation (ş)	11.25±7.94	10.48±8.39	10.03±8.05

4.2.4. Kinetic parameter results of 45 degree thrust phase. By comparing peak values of horizontal resultant and vertical ground reaction on turf with different traction in thrust phase (Table 5), it can be found that turfs with different tractions have significant effect on the two parameters ($p = 0.015$, $p < 0.001$). After checking, it can be found that the horizontal resultant force of turf with high traction is obviously higher than that with low traction ($p = 0.001$) and vertical force of turf with high and medium tractions is significantly higher than that with low traction ($p = 0.043$, $p < 0.001$).

Table 5. Peak vale horizontal and vertical ground reaction on turf with different traction in thrust phase (unit: BW, $n = 13$)

Parameter	Turf with low traction	Turf with medium traction	Turf with high traction
Horizontal resultant force	1.21±0.19	1.25±0.18	1.27±0.1
Vertical force	2.34±0.28	2.45±0.2	2.47±0.2

a: compared with turf with low traction, it is of significant difference; compared with turf with medium traction, it is of significant difference.

4.2.5. Results of linear start gravity acceleration. Turfs with particles of different densities filled in have no significant effect on gravity acceleration of players. Gravity acceleration indexes of starting process are of no significant difference on turfs with low ($12.49\,\mathrm{m}\pm1.98\,\mathrm{m}$), medium ($12.38\,\mathrm{m}\pm2.44\,\mathrm{m}$) and high ($12.95\,\mathrm{m}\pm2.61\,\mathrm{m}$) tractions ($p = 0.425$).

5. Conclusion

Translational traction tests are carried out in the study in terms of artificial turfs with three different filling densities. And rotational traction tests are undone due to limited experimental conditions. On the other hand, there are studies showing that translational traction is related with the existing of rotational traction, and when translational traction increases, the rotational traction will also increase proportionally. Results of the experiment suggest: the change of filling density has an obvious effect on the interaction surface of shoes and artificial turf. As the density of particles increases, the traction also increases. Different filling densities lead to the change of traction of the interaction surface but the movement form in side cut phase remains unchanged. The increasing of traction of interaction surface will contribute to the increase of ground reaction force, joint torque and other peak values, thus increasing the risk of injury. Traction increase resulting from the changed filling density will provide good braking and thrust force in side cut process, but movement performance of linear start movement is of no significant difference.

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