Comparison of Tennis and Running Shoe Traction on Different Surfaces

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Abstract

The goal of this experiment was to see if there are athletic shoe designs that are more effective for traction on varying surfaces or if the designs that are currently being used by athletes are indeed the best suited. Two types of shoes, the New Balance Fresh Foam X running shoe and the Asics Gel-Dedicate 7 tennis shoe, were each tested on a track surface and a tennis court surface with two different normal forces to obtain frictional force data. Since running and tennis shoes are designed with different movements and surfaces in mind, they have different types of traction, which means their friction forces should be unequal. By collecting frictional forces and normal forces, friction angles could be derived and used as a basis of comparison to see variations in the traction of the shoe sole and the surfaces. It was hypothesized that tennis and running shoes are both designed to be most effective for their sport which would be supported by larger friction angles of each shoe on their own surface.

This report aims to present the data obtained, the calculated friction angles for each shoe, and the analysis of the results' significance. It was found that the running shoes on the tennis court had the most friction, with a friction angle of 36 degrees. On the track, the running shoes had a friction angle of 34 degrees. Then, with the smallest angle sizes, the tennis shoes had friction angles of 27 degrees and 28 degrees on the track and tennis court respectively. These results went against the initial hypothesis. This paper will review the implications of the larger friction angles compared to the smaller ones, while also discussing possible reasoning for this occurrence.

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Introduction

If every sport was lined up, individually examined, and then compared, many obvious discrepancies would be found. One of the first to be observed would likely be where the sport is played—courts, grass fields, and racetracks look vastly different from one another. These differences affect the nature of how the sport is played—especially concerning performance and injury prevention—which makes understanding the surface materials important in designing equipment that maximizes athletes' play. For example, each sport has its own specialized footwear.

Shoes have multiple characteristics that make them unique and suited for their intended sport such as durability, shock absorbance, and breathability. However, the trait being focused on in this experiment is the soles and their impact on keeping the athlete grounded, reducing slippage, and maximizing traction.

Popular sports include tennis and running. Tennis courts are primarily made of concrete coated in acrylic resins, which allows low maintenance with respect to different climates and increased vapor transmission (*1*). Concrete is a brittle material and is therefore strong in compression, an important property when being used for athletic activities. Running tracks are made of synthetic rubber to promote stability, be soft enough to avoid injuries, and still be resistant to high temperatures or heavy rain (*2*).

With surfaces varying, what keeps an athlete grounded on one surface will not yield the same result on another surface. Generally, the sole material found in athletic footwear is carbon rubber (*3*) which means that most specialization appears in differences in tread patterns and the contact surface area of the sole on the ground. The key difference between a running shoe and a tennis shoe design is that running shoes provide traction for back-to-front movement. However, in tennis, athletes move not only forwards and backwards, but also side to side, so their shoes must give more traction laterally (*4*). To better support these motions, tennis shoe soles have more medial and lateral wear support while running shoes have heel sole support. Tennis shoe soles are thicker, smoother, and flatter than indoor athletic shoes, especially when made specifically for concrete courts (*3*). The soles of running shoes are thin, around 3 millimeters, and are made to be extremely flexible (*3*).

Each shoe design was chosen for athletes all over the United States in their respective sports. Professional, collegiate, and amateur levels stick to the shoe that has been worn by those before them. New, drastic changes in designs rarely occur and therefore it is assumed that these are the best suited for use on each surface. However, if this is proven wrong, new research could be conducted to find improved designs that advance performance or decrease injury. Since athletic footwear must also consider other components—such as durability, shock absorbance, and breathability—when being designed, the soles and the maximization of traction are possibly sacrificed in the effort of including or ameliorating these other components. However, the grip of the shoe is what provides the athlete's stability and is an important factor in increasing injury prevention. Therefore, the goal of this research project is to test tennis shoes and running shoes on their own and each other's surfaces to see if there are truly significant differences in traction.

Literature Review

This study evaluates the interaction between tennis shoes and running shoes on different surfaces. To understand and better discuss the results of this experiment, the distinctions in each shoe design must be identified.

Tennis Shoe Design

Tennis is a dynamic-heavy sport that requires running forwards, backwards, and sideways. Therefore, tennis shoes are designed to provide support for all these types of motions. Without sufficient traction between the outsoles and the court during each movement, players would not perform at desired speeds or could slip if moving too fast (6).

A study done at the University of Sheffield assessed a tennis shoe's traction on an acrylic hard court tennis surface in 4 main directions: forward (0 degrees), sideways (90 degrees), and at angles (30 and 60 degrees). They found that under normal loads ranging from 500 to 1000 newtons, the sideways movement produced the greatest values of frictional force, while the forward movement had the smallest (3). This supported the fact that tennis players' tendency to continuously move sideways and at angles during matches influenced the design of their shoe outsoles on their surfaces geared towards that movement.

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Running Shoe Design

Unlike tennis, running requires one motion: forward. Therefore, the design of these shoes supports traction for only that one movement. A study conducted at the University of Calgary used real athletes to test a running shoe specifically designed to have increased running traction against a control shoe that did not. They found that the control shoe had a coefficient of friction of 1.25 while the specifically designed shoe had 1.41 which, with the level of statistical significance being $\alpha = 0.05$, meant traction significantly improved (8). Like tennis, running shoe outsoles have been designed to be beneficial in regard to improving athletic performance and decreasing the likelihood of injury.

ASTM Standard:

There exists a standard test method used for traction characteristics of athletic shoe-sports surface interactions. The ASTM F2333-04 standard, reapproved in 2017, includes the necessary procedures and calculations to find the traction developed between shoe outsoles and surfaces during different movements athletes tend to make (5).

The test method requires a footform, a rigid, foot-shaped object, to be inserted into the test shoe and loaded with a normal force. While the research project presented in this paper will not use an exact foot-shaped object, it will apply weight in this manner.

Variables for each test shoe that need to be recorded prior to experimentation include the orientation of the outsole relative to the frictional force, the outsole pattern, and the loaded outsole surface area (5). Then, for testing, any machine enabling movement should be used to overcome the shoe-surface static friction and then cover some distance with a constant speed (5). The horizontal force applied to achieve this extended movement must be recorded and will represent the dynamic frictional force for that test shoe.

This ASTM standard is mainly meant to research relationships between traction and performance/injury or compare shoes within the same sport to develop focused outsoles. The difference is that the goal of this paper is to use two shoes from two different sports, running and tennis, on different surfaces to compare traction and gain insight into which is better suited for which surface. Therefore, some modifications to the experimental procedure, including normalizing by loaded surface areas, were made.

Running and tennis shoes have been experimentally proven to accommodate specific motions. However, no studies compare these two types of shoes on different surfaces and what variation in traction could occur. This paper aims to evaluate that comparison of traction.

Experimental Design

The purpose of the experimental portion of this research is to measure the frictional force between the shoe and the surface for different normal forces and different shoe designs. Two surfaces, one running shoe, and one tennis shoe were utilized.

Before the start of any trial, the weight of the running shoe was taken on a scale and recorded. Then, clay—shaped roughly into a model foot so that weight is distributed to the front of the shoe as well as the back—was placed in the shoe. More clay was added to the shoe's opening, simulating the placement of the rest of the body weight, so that the composite weight totaled 5500 grams (53.9 N normal force). Once loaded, the shoe was placed in a tray of Play-Doh. After 20 seconds, the shoe and its additional weight were removed from the tray and the indentions left behind were measured using a digital caliper with millimeter measurements. Shapes with known area formulas—for example, rectangles, triangles, parallelograms, and trapezoids—were used to approximate small sections and were summed up to give a total area. This represented the contact area of the shoe and the ground when under a normal force. This was then repeated with the same shoe but instead with the composite weight of the shoe and clay totaling 8500 grams (83.3 N normal force). This series of steps was then completed with the tennis shoe. This gave a total of 4 different surface areas calculated and recorded. Since finding these surface areas required a series of shape estimations to be made, most errors in this experiment will most likely be from this step. Therefore, these measurements were taken with a consistent tool so any error was uniform across both shoes and each normal force.

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Before the trials, surfaces were dried and cleared of dirt to reduce the number of variables. This allowed the data to be the most accurate representation of the traction between the shoe and the surface. For each individual trial, a shoe was placed on a surface with one of the

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previously measured amounts of clay so that the coinciding normal forces were achieved. A 50 N spring balance was then hooked to the shoe at the toe cap (Figure 1).

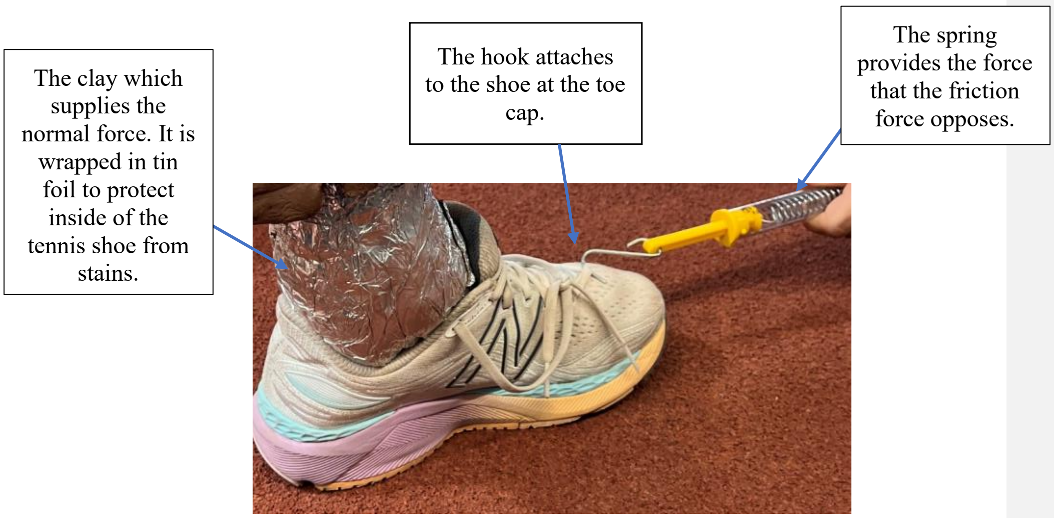
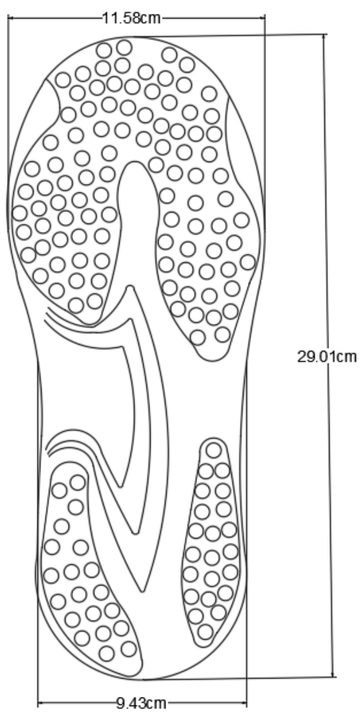


Figure 1: 50 N Spring Balance While Hooked to Running Shoe

The spring balance has tick marks on it which represent how much force is acting on the hook. When a force was applied, the spring pulled back and stopped at the corresponding tick mark. Therefore, that force reading, in newtons, was what was required to overcome the friction acting on the shoe between its sole and the surface while the shoe was in motion.

The spring balance, along with the shoe and applied normal load, was lightly pulled with increasing strength until the shoe began moving. Once this occurred, the shoe was displaced for an additional five seconds so that the spring balance exhibited dynamic friction and not static friction. This applied force was recorded after every trial.

The two types of shoes being tested in this experiment were the New Balance Fresh Foam X (size women's 8) running shoe (Figure 2) and the Asics Gel-Dedicate 7 (size women's 8) tennis shoe (Figure 3).



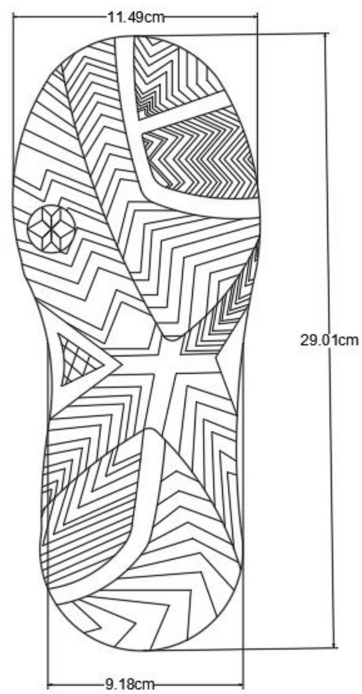


Figure 2: Running Shoe Tread **Figure 3:** Tennis Shoe Tread

The two surfaces that both shoes were tested on were an outdoor, concrete-based tennis court and an indoor, flat rubber surface track. Three trials of each shoe on each surface were completed with first the 53.9 N normal load and then the 83.3 N normal load, totaling 24 overall tests.

Methods and Theory

Once the frictional forces were collected experimentally, a means of data evaluation was determined. This was done by solving for variables to apply the Mohr-Coulomb equation and obtain the friction angle which can then be used to compare the different shoe and normal force combinations. The Mohr-Coulomb equation in its standard form is:

$$\tau = c + \sigma \tan(\phi) \qquad \text{(Equation 1)}$$

where τ is the shear stress (or shear strength), c is cohesion, σ is normal stress, and ϕ is the friction angle. The Mohr-Coulomb equation describes a linear relationship between shear stress and normal stress, which was plotted with the former on the vertical axis and the latter on the horizontal axis. The friction angle is represented graphically by the angle between the horizontal axis and the data set. Normal stress was solved for using its definition:

$$\sigma = F_N/A \qquad \text{(Equation 2)}$$

where F_N is the normal force—which was found by adding the mass of the object used to create the normal force and the mass of the shoe and then multiplying by the gravity on Earth's surface: 9.8 m/s^2—and A is the contact area between the shoe and the surface. There were four separate contact areas, one for each shoe under each normal force. The contact area was determined pre-testing when the shoe was placed in the tray of Play-Doh. To find shear stress, the definition of shear stress was also used:

$$\tau = F/A \qquad \text{(Equation 3)}$$

where F is the force pulling the shoe, which was displayed by the spring balance in Newtons and A is the contact area between the shoe and the surface.

It is reasonable to assume that cohesion is negligible, so a simplified version of the Mohr-Coulomb equation that will be used for calculations is:

$$\tau = \sigma \tan(\phi) \quad \text{(Equation 4)}$$

The basis of comparison for the different shoe types, surface materials, and normal forces will be the friction angle. Therefore, Equation 4 was rewritten to solve for ϕ:

$$\phi = tan^{-1}(\frac{\tau}{\sigma}) \quad \text{(Equation 5)}$$

Since running and tennis shoes are designed with different movements in mind, the friction angle was used to see variations in the traction of the shoe sole and the surfaces. A larger friction angle shows that there is greater traction while a smaller angle means less. By normalizing the normal force and frictional force by contact area, the friction angle can be compared more directly without other varying components involved.

Analysis and Results

The completion of the procedure produced two main data sets containing the frictional force measured at each testing site and the normal force measured before experimentation began. Using the methodology, the needed conversions were made. That new data allowed comparison graphs to be produced and variations in traction of each shoe to be quantitatively observed.

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The first specimen tested was the New Balance Fresh Foam X. The running shoe weighed 0.281 kg. Weight was added so that in total, the specimen's normal force was 5.5 kg (53.9 N) for two rounds of testing, one on the track and one on the tennis court, and then 8.5 kg (83.3 N) for the other two rounds. Under each normal force, the running shoe was tested three times to produce four average frictional forces (Table 1).

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Table 1: Collected raw data for the running shoe on two surfaces with two distinct weights.

Running Shoes					
		Frictional Force (N)			
Surface Material	Normal Force (N)	Trial 1	Trial 2	Trial 3	Average
Track	53.9	36	35	38	**36**
	83.3	54	55	55	**55**
Tennis Court	53.9	40	38	38	**39**
	83.3	64	62	61	**62**

Under the 53.9 N load, the contact area was 0.00565 m^2 while under the 83.3 N load, it was 0.00619 m^2. Using the average values and contact area for each normal force, shear stress and normal stress were calculated using Equation 2 and Equation 3. These new quantities can be found in Appendix A. Shear stress was then plotted against normal stress for the running shoes on the two surfaces where two positive linear relationships were observed (Figure 4).

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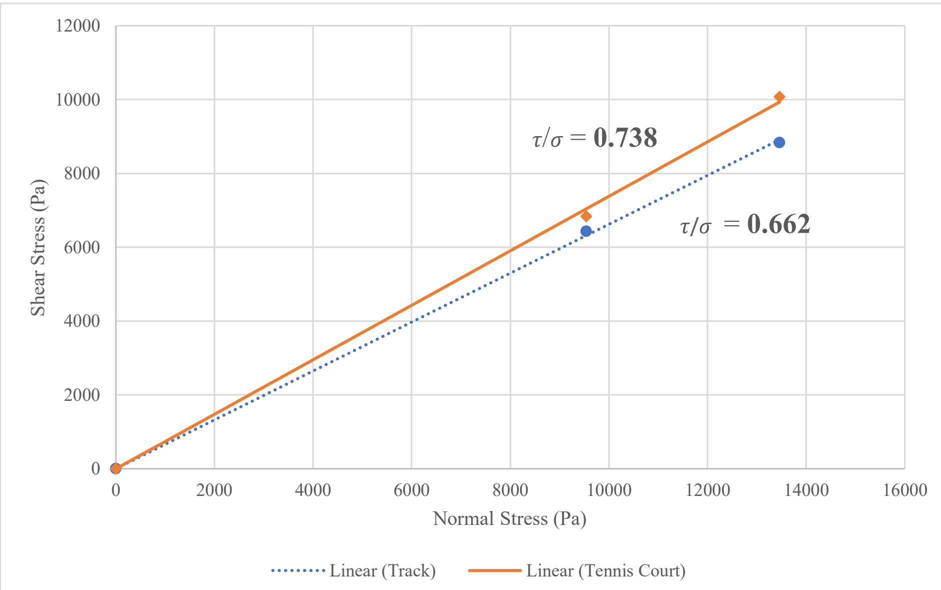

Figure 4: Shear Stress vs. Normal Stress for Running Shoe Traction.

The linear relationship between shear and normal stress follows the Mohr-Coulomb failure criterion. Therefore, the slopes in Figure 4 can be used in Equation 5 to produce the friction angles for the running shoe on each surface. For the track surface, the friction angle was

$$\phi = tan^{-1}(0.662)$$

$$\phi = 34°$$

For the tennis court surface, the friction angle was

$$\phi = tan^{-1}(0.738)$$

$$\phi = 36°$$

As seen by the larger friction angle, running shoes do not experience more traction on the surface it was made for, the track, than the surface it was not made for, the tennis court.

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However, there are only two degrees separating the two friction angles. This means that it was stated that the differences in friction are not significant.

The second specimen tested was the Asics Gel-Dedicate 7, with the same normal forces and conditions applied as on the running shoes. This testing also produced four average frictional forces (Table 2).

Table 2: Collected raw data for the tennis shoe on two surfaces with two distinct weights.

Tennis Shoes					
		Frictional Force (N)			
Surface Material	Normal Force (N)	Trial 1	Trial 2	Trial 3	Average
Track	53.9	24	21	24	**23**
	83.3	38	41	42	**40**
Tennis Court	53.9	40	38	38	**39**
	83.3	64	65	61	**63**

Under the 5.5 kg (53.9 N), the contact area for the tennis shoe was 0.0045 m^2 while under the 8.5 kg (83.3 N) load, it was 0.0051 m^2. These two values were then used to normalize the corresponding average frictional forces. These new quantities can also be found in Appendix A. The shear stress and normal stress were then plotted for the tennis shoes on the two surfaces in which positive linear relationships were once again observed (Figure 5).

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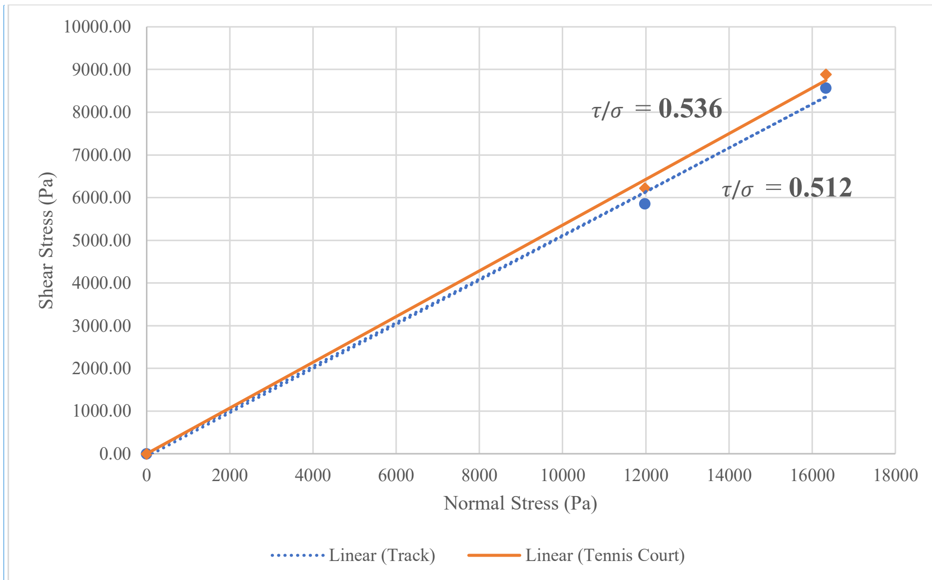

Figure 5: Shear Stress vs. Normal Stress for Tennis Shoe Traction.

This data was again used in Equation 5 to produce the friction angle for each surface's linear trendline. For the track surface, the friction angle was

$$\phi = tan^{-1}(0.512)$$

$$\phi = 27°$$

For the tennis court surface, the friction angle was

$$\phi = tan^{-1}(0.536)$$

$$\phi = 28°$$

Both angles are only separated by one degree, and therefore there is no significant difference between the traction of the tennis shoes on the two separate surfaces. This is the same trend as seen with the running shoes, however, there is an observable difference in the size of friction angles between the two shoes, with the average running shoe angle being 35 degrees and the average tennis shoe angle being 27.5 degrees. This can be explained by the fact that, in this experiment, only the forward motion was tested. It was found when reviewing literature that tennis shoes and running shoes are meant to support different types of motions. Therefore, since both tennis shoe friction angles were smaller than the two running shoe friction angles, the claim that running shoes are primarily designed for forward movement while tennis shoes are primarily designed for lateral movement is supported. However, the claim that the shoes are designed for their specific surfaces is not. This relation can be seen clearly when shear stress and normal stress were plotted again but now with both shoes tested on specifically the tennis court (Figure 6).

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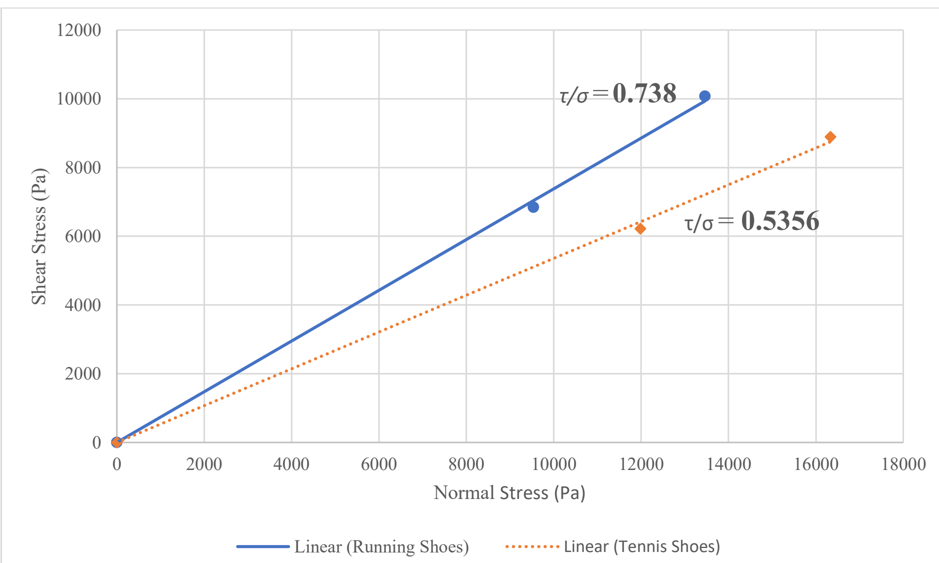

Figure 6. Comparing Running and Tennis Shoe Traction on a Tennis Court Surface.

The friction angles for each of these slopes have previously been calculated. However, Figure 6 offers a visual representation of the lack of support for the claim that shoes are designed for their specific surfaces since the running shoes have a larger friction angle than the tennis shoes even when they are both tested on the tennis court. The larger friction angle is a representation of more grip between the shoe and the surface. Theoretically, the tennis shoe should have the largest angle on the tennis court while the running shoe should have the largest angle on the track. However, this is not the case. The graphical representation that instead compares both shoes on the track can be found in Appendix B.

Conclusion and Recommendations

After testing both the running shoes and the tennis shoes on the track and tennis court with two different normal forces, it was found that the running shoes on the tennis court had the most friction, with a friction angle of 36 degrees. The running shoes also had the second-largest friction angle when tested on the track with an angle of 34 degrees. The tennis shoes had friction angles of 27 degrees and 28 degrees on the track and tennis court, respectively. Therefore, traction was not found to be different for a particular shoe for either surface.

The goal of this research was to find if tennis shoes and running shoes have significant differences in traction on their own and each other’s surfaces. This has proven not to be true. Earlier in this paper, it was questioned if the grip of the shoe is designed for the sport’s intended surface or if this was sacrificed for other components. While it cannot be proved that the result of this research was because of manufacturers ameliorating other aspects of shoe design, it can be stated that the traction of shoes is not specific to their surface.

One of the explanations for the result of this research was that shoes were only tested with a forward motion. This would allow the hypothesis that tennis and running shoes are designed to be most effective for that sport to be supported because the running shoe has more traction during forward movement than the tennis shoe.

Future researchers should consider the fact that tennis shoes are supposedly designed for a different direction of movement. Testing the shoes with a lateral force could result in the tennis shoes having greater friction and would show that any design differences are effective for their respective applications. An improvement to this experiment would be to have some kind of control group, such as a smooth surface material, that would allow the researchers to see how much friction the soles of the shoes create on their own when not assisted by the surface of the ground.

Appendix A

Tennis and Running Shoe conversion of Raw Data

Table 3. Running shoes calculated shear stress and normal stress from raw data.

Running Shoes					
		Shear Stress (Pa)			
Surface Material	Normal Stress (Pa)	Trial 1	Trial 2	Trial 3	Average
Track	9536.45	6369.43	6192.50	6723.28	6428.40
	13459.97	8725.55	8887.14	8887.14	8833.28
Tennis Court	9536.45	7077.14	6723.28	6723.28	6841.24
	13459.97	10341.40	10018.23	9856.64	10072.09

Table 4. Tennis shoes calculated shear stress and normal stress from raw data.

Tennis Shoes					
		Shear Stress (Pa)			
Surface Material	Normal Stress (Pa)	Trial 1	Trial 2	Trial 3	Average
Track	11977.78	5555.56	5555.56	6444.44	5851.85
	16333.33	8235.29	9019.61	8431.37	8562.09
Tennis Court	11977.78	6222.22	6666.67	5777.78	6222.22
	16333.33	8823.53	8627.45	9215.69	8888.89

Appendix B

Comparing Running and Tennis Shoes on a Track Surface

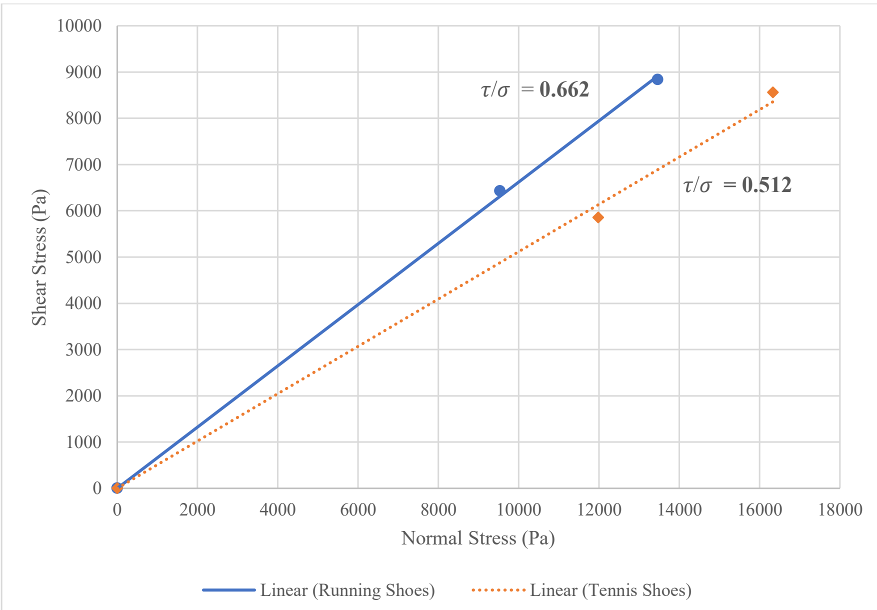

Figure 7. Comparing Running and Tennis Shoes on a Track Surface

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