EFFECT OF THREE SPIKE CONFIGURATIONS ON THE GROUND REACTION FORCES IN SPRING STARTS

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The effectiveness of sprinting is dependent upon sufficient traction between the feet and ground. Lack of such traction usually affects the balance in the movement of the body and slippage may occur. In order to investigate traction and effective movement, it is necessary to understand Newton's third law of motion, which states that for every action there is an equal and opposite reaction. For skill to be performed effectively, force production should involve the one-to-one correspondence between the force that is applied to the ground by the foot of a performer and the force that is being "used" during propulsion (Cavanagh and Kram, 1985). Few studies have been conducted by researchers to quantify the force production during sprinting and in the sprint start for the purpose of detecting and optimizing the performance of an athlete (Nett, 1964; and Cavanagh 1982). Despite a considerable amount of research involving force production during crouch start and sprinting (Payne and Bloder, 1970, Henry, 1952, Barlow and Cooper, 1972). A question of concern remains unanswered regarding the use of spikes in sprinting. What is the effect of spike configuration upon sprinting performance? Configuration is defined in this study as the shape and the length of the spike. While the shape is determined by the shoe manufacturing designer, the maximum length of an individual spike and the number of spikes, in each shoe are determined by the international rule. The rule is as follows: "the part of each spike which projects from the sole or heel must not exceed 9 mm in length."

The main focus of the study was to investigate the effect of three spike configurations on the ground reaction forces in the sprint start without using blocks. Secondarily, static coefficient of friction and traction characteristics were measured to determine the greatest contribution of the spike to the effectiveness of sprinting. The spike configurations that were used for the study conformed to the International Association of Amateur Athletics' rule regarding spike dimensions and numbers.

All kinds of spike configurations have the capability to provide traction between the shoe and ground. The degree to which spike configuration would affect traction was of concern. Therefore, it was hypothesized that there will be a difference in the traction forces for the three spike configurations.

METHOD

The protocol of the study encompassed two phases. The first phase consisted of field experimentations, whereas the second phase comprised laboratory experimentation.

Phase I. field experimentation

The field experimentation consisted of two test sessions, involving four subjects with 3 trials for each spike configuration on day one and one subject with 10 trials for each spike configuration on day 2.

Subjects

Four sprinters from the University High School (Champaign, Illinois) track team served as subjects on the first day. Two subjects were males, and two were females. They participated in the study on a voluntary basis and were told to bring their own sprint shoes. The subject on the second day was one of the females who was tested on day one.

Apparatus

Three spike configurations were used by each sprinter, and they were as follows: 1/4" cone "pointed"; 1/8" cone "pointed"; and 1/4" blunt (Figure 1). The equipment used for the study included the AMTI force platform system and software; and a long strip of rubberized mat that served as a running lane (the end part of it covered the force platform).

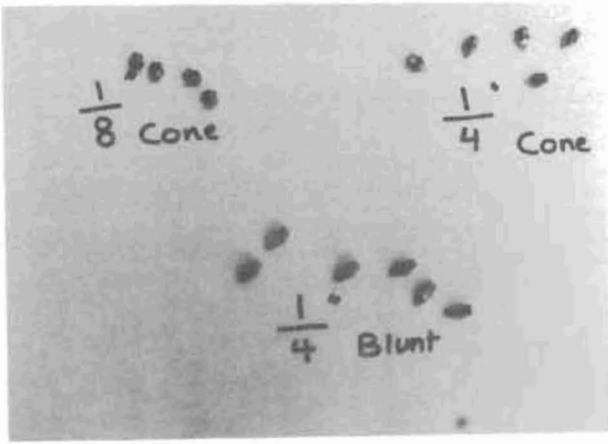

Figure 1
Spike Configurations

Procedure

Each subject was told to execute the following tasks while performing three trials with each spike configuration: Sprinting from the crouch position on the force platform (the crouch condition); and sprinting from the crouch position one step behind the force platform (the sprint condition). The sprint condition was the only condition used on day 2 by the subject. In this task, the rear leg of each subject landed on the force platform. For both tasks, each subject was told to execute a sprint start as fast as possible for the first 50% of the distance and decelerate

TABLE 1A

FIGURES IN NEWTONS FOR THE CROUCH CONDITION

	1/8" CONE			1/4" CONE			1/4" BLUNT		
SUBJECT I	112.0	213.4	223.3	95.9	187.4	196.2	108.0	206.8	215.7
	116.6	218.9	228.8	112.6	214.0	224.3	120.2	223.3	234.2
	120.7	221.2	233.3	111.5	202.0	213.8	111.1	208.5	220.2
SUBJECT II	116.0	225.0	235.9	79.2	159.7	171.8	78.5	157.7	173.2
	115.3	210.5	218.4	98.0	190.0	204.1	116.9	210.0	216.7
	113.0	203.0	214.0	81.7	165.4	172.8	100.8	197.0	209.7
SUBJECT III	150.7	281.5	293.2	144.6	281.9	293.1	145.4	276.3	287.1
	157.7	284.3	298.7	136.6	264.0	270.5	126.8	255.1	268.9
	163.5	303.9	310.3	139.8	277.1	282.8	132.6	250.4	262.6
SUBJECT IV	100.1	191.2	203.1	98.9	210.1	220.5	93.6	198.6	212.5
	98.3	198.8	209.6	102.5	205.8	216.6	96.9	203.0	213.5
	101.8	216.9	228.4	113.3	220.2	232.0	91.8	193.6	202.2
	Fx	Fx+Fz	Fx+Fz+Fy	Fx	Fx+Fz	Fx+Fz+Fy	Fx	Fx+Fz	Fx+Fz+Fy

TABLE 1B

FORCES IN NEWTONS FOR THE SPRINT CONDITION

	1/8" CONE			1/4" CONE			1/4" BLUNT		
SUBJECT I	117.0	248.4	272.1	104.3	224.4	247.4	93.8	227	235.0
	96.3	215.8	224.7	101.5	211.7	220.5	95.8	218.2	229.7
	117.0	259.0	271.3	89.3	206.3	223.6	91.8	210.7	224.2
SUBJECT II	115.7	247.7	257.2	.27.2	286.2	294.7	109.8	245.7	259.1
	115.1	245.1	258.4	135.9	293.6	306.4	126.0	285.3	300.3
	131.0	286.1	307.6	129.9	285.5	295.6	120.7	255.6	281.1
SUBJECT III	121.3	266.0	295.2	129.2	247.2	264.3	121.4	257.7	272.9
	115.0	255.2	270.1	130.0	276.3	301.4	124.9	275.1	292.4
	116.0	248.0	265.4	135.3	273.2	286.5	128.1	279.2	307.3
SUBJECT IV	88.8	204.9	229.7	90.9	236.4	255.0	108.1	264.3	283.0
	101.2	229.3	251.3	97.1	251.3	275.1	106.3	240.4	255.6
	107.6	254.1	276.7	81.1	210.8	227.9	109.0	277.1	294.8
	Fx	Fx+Fz	Fx+Fz+Fy	Fx	Fx+Fz	Fx+Fz+Fy	Fx	Fx+Fz	Fx+Fz+Fy

the next 50% for a total of 10 meters. Subjects were told to warm-up for five minutes before the actual test so that they could get adjusted to performing in the new surroundings. The reaction forces exerted on the force plate were recorded for each trial. The subject was told to assume the crouch position and the command "go" was given to signal the start. Based upon research by Henry (1952), the medium crouch start was selected for use by all subjects for all trials and conditions.

TABLE 2A

Mean Forces in Newtons for Fx in the Crouch Condition

	# TRIALS	X	S.D.	S.E.	MIN.	MAX.	F-PROB.
1/8" Cone	12	111.83	11.5	3.33	88.8	131.0	
1/4" Cone	12	112.64	20.4	5.89	81.1	135.0	.97
1/4"	12	111.30	12.9	3.73	91.8	128.1	

Mean Forces in Newtons for Fx + Fz in the Crouch Condition

	# TRIALS	X	S.D.	S.E.	MIN.	MAX.	F-PROB.
1/8" Cone	12	246.6	21.7	6.2	204.9	286.1	
1/4" Cone	12	250.2	32.2	9.3	206.3	293.6	.84
1/4"	12	253.0	24.9	7.2	210.7	285.3	

TABLE 2B

Mean Forces in Newtons for Fx + Fz in the Sprint Condition

	# TRIALS	X	S.D.	S.E.	MIN.	MAX.	F-PROB.
1/8" Cone	12	264.9	23.6	4.8	224.7	295.2	
1/4" Cone	12	266.5	31.4	5.6	220.5	306.4	
1/4" Blunt	12	269.6	28.6	5.3	274.2	307.3	

Mean Forces in Newtons for Fx in the Sprint Condition

	# TRIALS	X	S.E.	S.E.	MIN.	MAX.	F-PROB.
1/8" Cone	12	122.1	22.4	6.4	98.3	163.5	
1/4" Cone	12	109.5	21.4	6.2	79.2	144.6	.27
1/4" Blunt	12	110.2	19.1	5.5	78.5	145.4	

RESULTS AND DISCUSSION OF PHASE 1

Analysis of variance (ANOVA) statistical method was used to test the differences between the means of the forces for the three spike configurations. The forces that were exerted by all subjects in the x, y, and z directions are listed in tables 1a and 1b for each condition and spike configuration. Fx, fx + fz, and fx + fz + fy are the variables that are labelled in columns for each spike configuration in both the crouch and sprint conditions. Fx is the force that exerted by the foot backwards during the push-off, and fx + fz is a combination of the backward and vertical forces, respectively. Fx + fz + fy is the combination of the backward, vertical and lateral forces, respectively.

The means, standard deviations, standard errors, maximums and minimums of each variable for each spike configuration under the two conditions are included in table 2 a, b, c. The value for f probability is also listed for each variable. The probability level of P<.05 was selected to denote significance regarding the differences in the forces for all spike configurations.

The statistical analysis revealed no significant difference between the forces exerted by the subjects with respect to spike configurations for crouch and sprint conditions. Therefore, one can reject the hypothesis, nevertheless, differences existed in trials between subjects and within subjects in certain spike configurations may superceed the insignificant results (Table 1a).

Despite the intersubject and intrasubject differences, a couple of reasons are brought forth to explain the lack of significance in the statistical results. One reason may be the insufficient number of subjects participating in the study for the reliability of the results. Another reason may be that each spike type is somewhat similar to one another in physical dimensions and shape, and there appeared to be no significant difference in the way each type of spike interacted with the rubber mat during force production. The mat used for the study was about 1/2" thick, and the maximum height of the three spike configurations was 1/4".

Results of day 2

Since intrasubject differences were large, one of the subjects performed 10 runs from the sprint condition for each spike configuration. The mean and the standard deviation are included in (Table 3). A T test statistical method was used to test the differences between the means of the forces for the three spike configuration. There were no significant differences between the mean forces when the subject used the 1/4" blunt and the 1/8" pointed spikes (111.3, 109), respectively. There was, however, a significant difference between the forces of 1/4" pointed and 1/8" pointed spikes (p = .04) at probability level of P<.05). The difference between the mean forces of spikes, 1/4" pointed and 1/4" blunt, approached significant (P = .08). This difference is meaningful only for this subject at P< .10.

There appears to be an interaction between the length and the shape of the spikes. An optimum length with an optimum shape may be of primary importance to provide an optimum traction. In other words, the shape alone is not isolated frpm the length and vice versa.

Phase II. laboratory experimentation

Since less results were obtained form the field experiment, which involved human subjects, may not be repeatable with other sample sizes or skill level, laboratory experimentation was performed as phase II of this study. Using such experimentation researchers can eliminate human subject variability and control or isolate the variables affecting the results.

Apparatus

The equipment consisted of Spring Scale to record tengential force, weights of 25 lbs each which were placed on the shoe, two surfaces for interaction with shoe: smooth metal platform; a piece of rubberized mat placed over the platform, and a VHS videography system to monitor the procedure.

Procedure

The test was initiated by placing a 50 lb weight on the sprint shoe (Figure 2). The shoe with the weight was put on the smoothed surface first. One end of the spring scale was hooked over the heel counter of the shoe. The investigator pulled horizontally the hook on the other end of the spring scale. There were five pulls for each spike configuration. As the pull occurred, the needle pointer of the scale measured the tangential force. At the onset of sliding, value from the scale was recorded simultaneously by the video system. The test was repeated using the same procedure with the rubberized mat as the interacting surface.

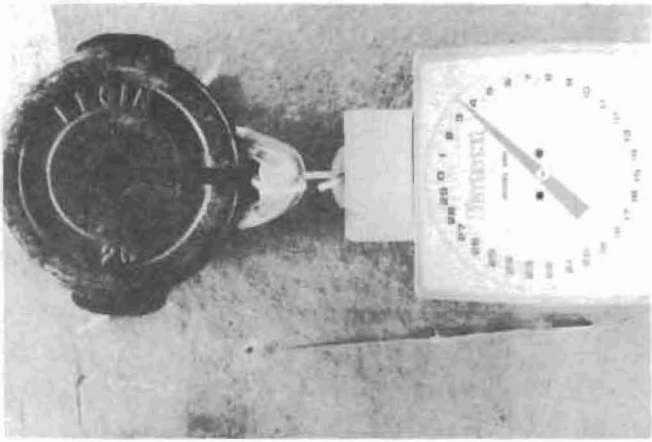

Figure 2
Spring Scale

RESULTS AND DISCUSSION PHASE 2

The average values obtained from the scale at the onset of the sliding for the two surfaces were as follows:

	Spike	Force
Smooth Metal Surface	1/4 Blunt	22
	1/4 Pointed	28
	1/8 Pointed	28.5

	Spike	Force
Rubberized Surface	1/4" Blunt	42
	1/4" Pointed	42
	1/8" Pointed	36

TABLE 2C

Mean Forces in Newtons for Fx + Fz + Fy in Crouch Condition

	# TRIALS	X	S.D.	S.E.	MIN.	MAX.	F-PROB.
1/8" Cone	12	230.6	37.3	10.7	191.2	303.9	
1/4" Cone	12	214.8	40.3	11.6	159.7	281.9	.49
1/4" Blunt	12	215.0	32.0	9.2	157.7	276.3	

Mean Forces in Newtons for Fx + Fz + Fy in Sprint Condition

	# TRIALS	X	S.D.	S.E.	MIN.	MAX.	F-PROB.
1/8" Cone	12	241.4	37.2	10.7	203.1	310.3	
1/4" Cone	12	224.8	9.4	11.3	171.8	293.1	.48
1/4"	12	226.3	31.8	9.1	173.2	287.1	

TABLE 3

Results of Day 2

Variables: FX

SEI	N	MEAN	STD. DEV.	STD. ERROR	MIN.	MAX.	PROB > T
1/4 Cone	10	117.8	9.77	3.09	95.90	130.80	0.04
1/8 Cone	10	109.5	6.56	2.07	97.40	117.80	0.03
1/4 Blunt		111.3	8.37	2.88	99.5	125.9	.08

TABLE 4

Static Coefficient of Friction

	1/4 Blunt	1/4 Pointed	1/8 Pointed
50 lb over a shoe with smoothed surface	.44	.56	.57
25 lb over a shoe over rubberized surface	1.68	1.68	1.44

The static coefficient of frictions were calculated by dividing the tangential force over the normal force (weight on shoe) which are shown in (Table 4). There is an obvious difference between the spike of the 1/4" Blunt and the other two spikes, (1/4", 1/8" Pointed), when they were placed on the smooth metal surface. These results are peculiar to each spike shape characteristic. For example, the two pointed types 1/4" & 1/8" have similar values. However, when the test was conducted on the rubberized surface, the results for the two spikes of the 1/4" length with different shapes (Blunt and Pointed) were almost identical. Thus the length of the spike is crucial. Although the pointed spike of 1/8" slid at lower corresponding values than the other two spikes, the difference is not "biologically significant" since all the static coefficients of friction are extremely high (Table 4). None of the spikes would slip under normal circumstances in sprint competition. The penetration of each spike to the rubberized surface is an important factor influencing slippage. Therefore, the short length of the 1/8" spike, may be considered a factor that influences its early slippage. Thus the frictional (shearing) forces may be insignificant compared to the reactive forces of penetration. Traction, then is the term to describe the combination of penetration and shearing forces. These two factors, in turn, create greater resistance to slip and greater effectiveness of shoe spike surface interaction.

CONCLUSION

From the results of the field experiment and the lab test, a provisional conclusion could be drawn. Spike configuration with lengths less than 9mm provide an equal and sufficient grip between the shoe spike and the track surface, especially if penetration has occurred. Differences in the ground reaction forces are probably due to strength differences at take-off between and among the individual subjects.

In order to understand the effects of actual push against supporting surface, tests must be conducted to include a horizontal/vertical diagonal pull. This simulation could be done by using a thrust device. The shoe is thrusted along the slanted force platform by a thrust machine.

REFERENCES

Barlow, D.A., and Cooper, S.M. (1972): Mechanical considerations in the sprint start, Athletic Asia 2: 27.

Cavanagh, P.R. and Kram R. (1985). The efficiency of human movement - a statement of the problem. Medicine and Exercise in Sports and Exercises, 17: 304-308.

Cavanagh, P.R. (1982). The shoe-ground interface in running. American Academy of Orthopedic Surgeons. Symposium on the foot and leg in running sports. Editor Robert P. Mack.

Henry, F.M. (1952). Force-time characteristics of the sprint start. Research Quarterly, 301-318.

Nett, T. (1964). Foot plant in running. Track Technique, 15: 462-463.

Payne, A.H. and Blader, F.B. (1972). A preliminary investigation into the mechanics of the sprint start. Bulletin of Physical Education 21-30.