Friction Blisters and Sock Fiber Composition

*A Double-Blind Study**

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A longitudinal double-blind study was conducted to determine the effect of sock fiber composition on the frequency and size of blistering events in long-distance runners. Thirty-five long-distance runners participated in this study. Two different socks were tested, which were identical in every aspect of construction except fiber composition. One test sock was composed of 100% acrylic fibers, and the other test sock was composed of 100% natural cotton fibers. The results showed that acrylic fiber socks were associated with fewer blistering events and smaller blisters (mm^2), when compared directly to cotton fiber socks.

Blistering of the feet is one of the most common injuries sustained by the runner during racing and training.[1-8] While considered by most runners to be an insignificant injury, blistering frequently leads to a compromise of individual performance, particularly during the acute stages of blistering.[9-11] Complications from blistering in runners include infection, aplastic anemia, and epidermolysis bullosa simplex.[7,12,13]

A blister is defined as an intraepidermal event in which a cleavage occurs in the mid or upper malpighian layer with an intact stratum corneum, stratum lucidum, and stratum granulosum blister roof. The stratum basalis remains relatively undamaged and intact.[13] Studies have shown that a blister will appear on plantar skin when rapidly applied shearing forces separate the stratum corneum, stratum lucidum, and stratum granulosum from the stratum spinosum.[6,12,14-18] A fluid-filled vesicle results, containing cells from the stratum granulosum and stratum spinosum.[14] Experimental studies have also shown that blisters cannot be artificially produced except on an integument that has a thick stratum corneum.[19] Therefore, friction blisters are peculiar to the skin of the palms of the hands and soles of the feet where the thickened stratum corneum, stratum lucidum, and stratum granulosum develop a movement interface with the deeper stratum spinosum.

Health professionals, coaches, and athletic trainers have identified several etiologic factors in the formation of friction blisters on the feet of runners. Shoe gear that is either ill-fitting, worn out, or poorly designed has been most commonly implicated as the major causative factor of blisters on runners.[3,4,6,8,17,19-24] Improper or ill-fitting socks have also been known to be an important causative factor in the development of friction blisters.[1-3,9,19,24,25]

Dynamic shearing forces are necessary for the formation of friction blisters on the feet.[18,19,26] Spence and Shields[18] identified four types of dynamic forces that can be associated with running

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gait and blisters: vertical forces, fore and aft shear, lateral shear, and torque.

Various measures have been recommended to runners for the prevention of blisters on the feet, including debridement, the use of padding and cushioned insoles, as well as the application of petroleum jelly to the feet, tincture of benzoin spray, and application of tape to the feet.[1, 2, 5, 10, 18, 20, 21, 23, 25,27] Recommendations for the prevention of blisters have included wearing two pairs of socks to a preference for socks composed of cotton fibers.[1–3, 8, 10, 12, 20–23, 27]

In a search of the literature, no scientific evidence could be found to substantiate the superiority of one sock fiber over another in the prevention of friction blisters. Health professionals and coaches continue to make recommendations for proper socks based upon anecdotal rather than scientific information. Thus, a study was undertaken to compare the efficacy of the two most popular athletic sock fibers to determine if one fiber had a superior function in terms of blister prevention among long-distance runners.

Materials and Methods

Project Participants. Sixty runners from the San Francisco and Los Angeles, California, areas participated in this study. These runners represent a broad cross section of recreational long-distance runners, taking into account experience, frequency of training, lower extremity biomechanics, and frequency of blistering.

To participate, each runner was required to be an avid runner, in good physical health, and not currently under the care of a doctor or other health care professional for an acute running-related injury. On initial inquiry, each runner was screened by an informal interview, written questionnaire, and biomechanical evaluations of the lower extremity. For consistency, the biomechanical evaluations of 24 runners were conducted by podiatrists specializing in sports medicine, and 36 evaluations were conducted by a resident in biomechanics at the California College of Podiatric Medicine.

Runners were eliminated from the project based upon the following criteria: intrinsic structural or mechanical problems that were believed to contribute to blister formation, including well developed plantar keratoma, more than 7° of uncontrolled forefoot valgus, more than 8° of uncontrolled rearfoot varus, first ray range of motion less than 2 mm dorsiflexion, a resting calcaneal stance position exceeding 5° everted, or ankle joint dorsiflexion less than 5° with the knee extended or less than 10° with the knee flexed; a personal history of unilateral blisters; and marked small feet (men size less than 6 and women size less than 7). Each of the selected runners was given specific instructions regarding accurate data collection, care and laundering of the test socks, and running limitations.

Sock Description. Each participant was issued two pairs of THOR•LORI®[1] XJ-13 cotton socks and two pairs of THOR•LO XJ-13 acrylic socks. The runners and principal investigator were unaware of the fiber content of either sock. The socks were color coded to allow rapid identification, with a mint stripe representing cotton fibers and a yellow stripe representing acrylic fibers.

The fibers used to knit the cotton socks included 14/2 100% cotton with extra link 2 ends in top and 14/2 100% cotton double yarn in the sole. Additionally, 7074 AT spandex with a core of 210 denier, a top cover of 70/34 textured nylon ("2" twist), and bottom cover of 70/34 textured nylon ("s" twisted) was used for elasticity. This knitting resulted in a THOR•LO XJ-13 mint green 289 stripe sock with a finished size of $9^{5}8^{0}17^{6}$ (Thorneburg Hosiery Co., Inc., Cotton and wool *versus* acrylic task force, 1987). The fibers used to knit the acrylic socks included 2/20 100% acrylic with extra link 2 ends in the top and 2/20 double yarn in the sole. Also, 7074 AT spandex, identical to that used for knitting the cotton socks, was used in the knitting of the acrylic socks. The resulting THOR•LO XJ-13 yellow 17 acrylic socks had a finished size of $9^{5}8^{0}17^{5}$ (Thorneburg Hosiery Co., Inc., Cotton and wool *versus* acrylic task force, 1987).

The socks were knit on 4½-inch knitting machines. Every possible effort was made during the knitting and finishing process to produce as nearly identical socks as possible. The resulting socks issued to the runners were not noticeably different in quality, comfort, bulk, or fit.

Experimental Design. Data was collected from a series of four experimental run-trial segments. Each segment reflected a specific sock combination: A, right foot cotton and left foot cotton; B, right foot cotton and left foot acrylic; C, right foot acrylic and left foot cotton; and D, right foot acrylic and left foot acrylic.

The homogeneous cotton and acrylic fiber combinations tested were used to establish differences in sampling data attributable to right foot *versus* left foot, while the heterogeneous cotton and acrylic fiber combinations tested were used to establish

®[1] Thorneburg Hosiery Co., Inc., Statesville, NC.

differences in sampling data attributable to sock fiber composition.

Each of the four experimental segments correspond to a series of five to ten runs conducted over a period of 10 to 30 days. This design provided each runner some individual flexibility with which to rest, cross-train, or continue running, and it set limits for the duration of data collection.

The basic data collecting unit was called a run. Each was identified by one of the four sock combinations (A to D) and a numerical value associated with its sequential position within the 5 to 10 replicates for that segment. Once the runners began testing a specific sock combination, they would continue with that combination until they had completed the required 5 to 10 replicates. Only at this time would a new sock combination be started.

Each run replicate lasted a minimum of 45 min but no more than 180 min. In preparation for each replicate, runners were asked to launder, dry, and inspect the appropriate socks and inspect their feet. Upon the conclusion of each replicate, the runners would reexamine their socks and feet, documenting the before and after run data. If, following a replicate, a blister of grade 3 or higher was documented, the runner was asked to cease data collection for a minimum of 2 days. No attempt was made to control any of the runners' personal training habits, including training surface or training regimen. Shoe fit and condition were controlled only to the extent that proper fit and condition of the shoes to be used were confirmed at the time of sock dispersement. Numerous other variables exist; of these, age, sex, weight, body type, and running gait were not controlled.

Blister Evaluation. At the conclusion of each replicate, the runners examined both socks used and their feet. The sock examination consisted of two parts, and included a brief before-run evaluation and an after-run critique. Important points identified included cushioning properties, dampness and temperature characteristics, sock-shoe adhesions, and fiber resiliency to wear.

The foot examination conducted by each runner focused on areas of skin irritation and injury. Each runner collected parametric and nonparametric data. In this manner the runners could collect meaningful data rapidly without sacrificing quality. To collect parametric data, runners used a millimeter ruler to measure (to the nearest millimeter) the greatest dimension (length *versus* width) of all areas of skin injury. Additionally, each runner reported the anatomical location of each blister. Nonparametric data was collected by relying on a psychological scaling or rating process.[28] For areas of blistering, the following scale of severity was used: grade 1, no post-run redness and no pain (a blister "hot spot"); grade 2, post-run redness and no pain; grade 3, post-run redness, loose surface skin, and pain; grade 4, post-run redness, an elevated and fluid-filled pocket of surface skin, and pain; and grade 5, post-run redness, broken surface skin or an elevation and blood-filled pocket of surface skin, and pain.

Additional data collected by runners following each run replicate included during-run sock padding, shoe-sock adhesions, post-run foot and sock dampness, and during-run foot temperature. To evaluate padding and adhesion characteristics, the runners were asked to respond to simple yes or no questions. Psychological scaling systems were used by runners to evaluate dampness and temperature. The following represents the five-point rating scale used for dampness: grade 1, dry; grade 2, damp; grade 3, moist; grade 4, wet; and grade 5, soaked. For temperature, the following five-point rating scale was used: grade 1, cold; grade 2, cool; grade 3, warm; grade 4, hot; and grade 5, unbearably hot.

In this study, Stats Plus®[2] and Analytical Graphics®[2], along with an Apple IIe®[3] computer, were used for all data base management and statistical analysis.

Results

A total of N = 60 runners participated in this study. Of this group, 25 runners terminated data collection for a variety of reasons, including loss of the data, loss of interest, injury, and severe illness. Thirty-five runners satisfactorily completed the necessary replicates for all four sock combinations. This group, thus, became the sample population and included 21 males (mean age = 34.4 years) and 14 females (mean age = 29.1 years). Table 1 provides a demographic profile of these runners.

The mean duration of all runs for each sock combination is reported in Table 2. These values do not appear to favor any one sock combination. Nor do the mean durations appear to be influenced by the number of replicates in each sock combination.

A total of N = 493 blisters were reported from 891 run replicates. These blisters were noted to be distributed in the following manner: 60.2% (297) of the blisters were reported on the forefoot; 33.3% (164) of the blisters were noted on the midfoot; and

®[2] Human Systems Dynamics, Northridge, CA.
®[3] Apple Computer, Inc., Cupertino, CA.

Table 1. A Demographic Profile of N = 35 Runners with Mean and Standard Deviation Included for Each Category[a]

	Sex	
	Male (N = 21)	Female (N = 14)
	Mean (SD)	Mean (SD)
Age (years)	34.4 (10.4)	29.1 (9.6)
Training history		
Experience (years)	8.5 (6.8)	8.7 (3.8)
Frequency (days/week)	5.6 (0.92)	5.9 (1.1)
Distance (miles/day)	6.5 (2.4)	6.6 (2.8)
Pace (min/mile)	7.3 (0.71)	8.0 (1.0)
Shoes		
Age (months)	4.9 (5.5)	7.1 (5.5)

[a] To be included, each runner successfully completed runs using each of the four designated sock combinations.

Table 2. Blister Frequency Distribution by Anatomical Area and by Sock Combination

	Sock Combination			
	Cotton (L) Cotton (R) N = 263[a]	Acrylic (L) Acrylic (R) N = 240	Acrylic (L) Cotton (R) N = 192	Cotton (L) Acrylic (R) N = 196
Duration[b] (min)	51.6	53.8	57.6	53.8
(Standard deviation)	(19.5)	(19.4)	(21.4)	(18.6)
Number of blisters				
Left forefoot	43	30	24	46
Right forefoot	53	33	34	34
Left midfoot	36	19	7	14
Right midfoot	40	20	19	9
Left rearfoot	5	4	0	10
Right rearfoot	4	5	0	4
Left foot total	84	53	31	70
Right foot total	97	58	53	47

[a] N, number of replicates.
[b] Mean, in minutes, and standard deviation of run duration for each sock combination.

6.5% (32) of the blisters were reported on the rearfoot. Table 2 provides a breakdown of the blistering events by anatomical area, specific foot (right or left), and by sock combination.

Runners evaluated basic physical properties that could be directly related to the fiber composition of the socks in question. These included an evaluaton of adhesive characteristics of the sock to shoe and padding provided by the sock during running, foot dampness, sock dampness, and foot temperature. For all sock combinations, the runners were unable to detect any significant difference in the level of adhesion or padding at a level of significance greater than 95%. Thus, any differences that were reported can be accounted for by random variability.

Runner dampness rating values for the foot and the sock were evaluated with Wilcoxon's signed-ranks test, which compared the reported paired ranking for left *versus* right foot.[29, 30] In this manner, the paired nonparametric data could be evaluated in a manner similar to a paired comparisons t-test.[29] Although it is more efficient to apply the corresponding parametric t-test, the data does not meet the assumptions of parametric techniques. The results are reported as P = probability values of the specific event occurring by random chance. A low P-value suggests that the observed difference in matched pairs was the result of factors other than random chance. When dampness was rated for homogeneous sock combinations, ie, cotton *versus* cotton and acrylic *versus* acrylic, the runners were unable to detect a significant difference in foot or sock dampness (Table 3). When the runners rated foot and sock dampness for heterogeneous sock combinations, ie, cotton (L) *versus* acrylic (R) or acrylic (L) *versus* cotton (R), a significant difference was detected for both categories of dampness with cotton (L) *versus* acrylic (R) (Table 3) . These results suggest, at least for foot dampness, that runners generally evaluated acrylic fiber socks as promoting a drier foot than cotton fiber socks.

The sensation of temperature surrounding the foot was rated by the runners. Wilcoxon's signed-ranks test was used to compare the reported ranking for left foot *versus* right foot (Table 4).[29, 30] The runners consistently associated acrylic fiber socks with a warmer foot environment. A summary of the dampness and temperature data based upon calculated mean values suggests that when heterogeneous sock combinations were worn, the runners noted a difference between left and right feet. Cotton fibers were noted as being associated with a damper foot, damper socks, and a cooler foot (Table 5). On the other hand, acrylic fiber socks were associated with a drier foot, drier socks, and a warmer foot (Table 5).

The distribution of grouped cotton *versus* acrylic rating data for foot dampness, sock dampness, and foot temperature was evaluated by organizing the data into multi-way contingency tables and testing the observed frequency distributions with multi-way χ^2 tests for independence and goodness of fit.[29] The results are reported as P = probability values, with a low P-value suggesting a high degree of independence and a low level of goodness of fit. More simply stated, a low P-value suggests that

Table 3. Results of Wilcoxon's Signed-Ranks Test of Homogeneous and Heterogeneous Sock Combinations for Foot and Sock Dampness Ratings[a]

Combinations	Z	P
Cotton left foot Cotton right foot	−1.34	0.1766
Acrylic left foot Acrylic right foot	−1.26	0.205
Acrylic left foot Cotton right foot	−2.43	0.0146
Cotton left foot Acrylic right foot	2.31	0.0198
Cotton left sock Cotton right sock	−0.91	
Acrylic left sock Acrylic right sock	−2.24	0.024
Acrylic left sock Cotton right sock	−2.86	0.004
Cotton left sock Acrylic right sock	2.69	0.007

[a] These results are organized by sock combination and both the Z-value and P = probability value for each combination are provided.

Table 4. Results of Wilcoxon's Signed-Ranks Test of Homogeneous and Heterogeneous Sock Combinations for Foot Temperature Rating[a]

Combinations	Z	P
Cotton left foot Cotton right foot	−1.48	0.1350
Acrylic left foot Acrylic right foot	−.34	
Cotton left foot Acrylic right foot	−3.83	0.001
Acrylic left foot Cotton right foot	−2.07	0.037

[a] These results are organized by sock combination and both the Z-value and P = probability value for each combination are provided.

Table 5. A Summary of Sock Characteristics for All Individual Run-Trials that Resulted in a Blister[a]

		Rating Scale		
Sock Combinations	N	Dampness to Feet (SD)	Dampness to Socks (SD)	Temperature to Feet (SD)
Cotton left foot	84	2.36 (0.80)	2.65 (0.92)	3.44 (0.66)
Cotton right foot	97	2.44 (0.76)	2.63 (0.90)	3.47 (0.69)
Acrylic left foot	53	2.38 (0.76)	2.51 (0.74)	3.45 (0.54)
Acrylic right foot	58	2.34 (0.83)	2.60 (0.77)	3.52 (0.50)
Acrylic left foot	31	2.34 (0.79)	2.44 (0.88)	3.22 (0.61)
Cotton right foot	53	2.39 (0.73)	2.59 (0.86)	2.86 (0.79)
Cotton left foot	70	2.60 (0.74)	2.77 (0.81)	3.0 (0.79)
Acrylic right foot	47	2.36 (0.83)	2.53 (0.89)	3.42 (0.58)

[a] Results are organized by sock combination and foot. Values reported include the mean and standard deviation of ratings for the aspects of foot dampness, sock dampness, and foot temperature.

observed rating values, as reported by runners, did not appear in the data with a uniform distribution pattern, and a runner's rating of one sock was considerably different from that of the other sock.

The results of χ^2 tests on grouped data for foot dampness, sock dampness, and foot temperature by fiber type suggest that runners were able to detect a significant difference in foot dampness between cotton and acrylic fiber socks ($P = 0.02$); able to detect a highly significant difference in sock dampness between cotton and acrylic fiber socks ($P < 0.001$); and unable to detect any significant difference in foot temperature between cotton and acrylic fiber socks ($P > 0.1$).[29,30]

The frequency distribution of reported blisters was evaluated by sock combination and by foot with the use of a multi-way χ^2 test.[29,30] When these data were further subdivided to more clearly identify the number of blisters by sock combination and severity, it was noted that severe blisters of grade 5 were relatively uncommon when compared to the incidence of minor blisters of grade 1. Although these results were true regardless of fiber type, the overall distribution of blisters as presented in a χ^2 table (Table 6) suggest that the observed distribution of blisters among all sock combinations was significantly different ($P = 0.01$).[29,30]

Figure 1 represents a frequency distribution histogram of blister severity for all cotton fiber sock blisters and acrylic fiber sock blisters regardless of foot. The distribution of these data clearly suggests that severe blisters of grades 4 and 5 were uncommon, resulting in a general skewing of the distribution toward the less severe end of the rating scale. Figure 1 suggests that cotton fiber socks are associated with a consistently higher frequency of blistering than acrylic fiber socks.

A blister ratio was calculated (Table 7). This hypothetical value provides a tool that allows the two sock fibers to be compared. When blistering events are viewed in this manner, the results suggest that runners wearing cotton socks experienced

Table 6. The Results of χ^2 Test for Goodness of Fit for the Observed Distribution of Friction Blisters Among All Sock Combinations[a,b]

	Sock Combination				
	Cotton (L) Cotton (R)	Acrylic (L) Acrylic (R)	Acrylic (L) Cotton (R)	Cotton (L) Acrylic (R)	Totals
Left foot					
Observed frequency	84	53	31	70	238
Expected frequency	87.4	53.6	40.6	56.5	
χ^2	0.1	0	2.2	3.2	
Right foot					
Observed frequency	97	58	53	47	255
Expected frequency	93.6	57.4	43.4	60.5	
χ^2	0.1	0	2.1	3.0	
Totals	181	117	84	111	493

[a] Values reported include the observed and expected frequency distributions for each of the four sock combinations. The χ^2 value and its df = degrees of freedom, in addition to the associated P = probability, are provided.
[b] χ^2 (df = 3) = 10.86; P = 0.01.

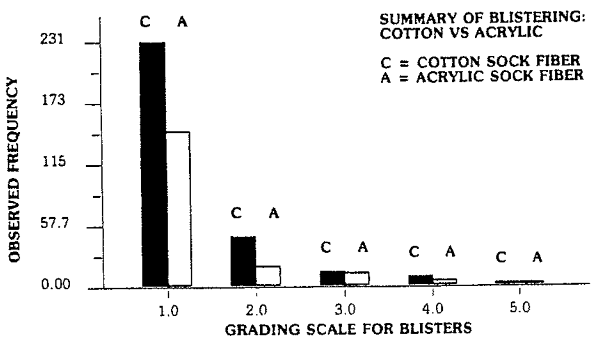

Figure 1. A frequency distribution histogram representing a summary of friction blisters when the data is grouped by sock fiber, cotton *versus* acrylic.

Table 7. A Summary of Blistering Tendency for all Runs, With Separate Results for Each Sock Combination[a]

	Measures of Blistering Tendency			
	N = Runs	N′ = Blisters	Blister Ratio	Mean Blister Size (mm²)
Cotton (L) *versus*	263	84	0.319	17.6
Cotton (R)	263	97	0.369	11.7
Acrylic (L) *versus*	240	53	0.221	8.7
Acrylic (R)	240	58	0.242	11.5
Acrylic (L) *versus*	192	31	0.161	14.9
Cotton (R)	192	53	0.276	39.5
Cotton (L) *versus*	196	70	0.357	81.2
Acrylic (R)	196	47	0.240	12.7
Cotton fibers *versus*	914	304	0.333	33.5
Acrylic fibers	868	189	0.212	11.2

[a] Results grouped by sock fiber, cotton *versus* acrylic, appear at the bottom of the table. Values reported include the number of replicates (N), the number of reported blisters (N′), the blister ratio (N′/N), and the mean blister size in mm².

a larger blister ratio (ranging from 0.28 to 0.37) and were more prone to blistering, with an overall 33% chance of blistering during any single run. Acrylic fiber socks, on the other hand, were associated with a lower blister ratio (ranging from 0.16 to 0.24) and only a 21% chance overall of blistering during any run (Table 7).

When blister size was calculated for each of the four sock combinations, cotton fiber socks, in general, were associated with larger mean blister sizes, ranging from a low mean value of 11.7 mm² to a high mean value of 81.2 mm². Acrylic fiber socks were associated with smaller mean blister sizes, with a range of mean values from a low of 8.7 mm² to a high of 14.9 mm² (Table 7).

When mean blister size was calculated for data grouped by sock fiber, cotton socks were associated with a mean blister size of 37.5 mm², while the acrylic socks were associated with a mean blister size of only 12 mm² (Table 7). The difference between these two means is approximately threefold and could reflect an intrinsic influence related to the experimental design. In an attempt to identify and isolate the factor or factors responsible for the observed difference in blister size, a two-way analysis of variance of blister size in mm² was applied to the data.[29,30] The results suggest the following: no significant difference in blister size could be attributed alone to right *versus* left foot (P = 0.19); a significant difference in blister size could be associated with the selection of the fiber type in a given sock (P = 0.01); and a significant difference was detected for the combined influence of sock fiber type and foot (P = 0.002) (Table 8).

Discussion

Blistering is a response of the skin to rapidly applied shearing forces that occur during normal run-

Table 8. A Two-Way Analysis of Variance of Blister Size (mm^2), in Which the Data Are Organized by Fiber Combination and Foot[a]

Source of Variation	df	SS	MS	F
Fiber combination[b]	3	87636.7	29212.2	3.31
Foot[c]	1	14820.0	14820.0	1.68
Fiber combination × foot[d]	3	128258.7	42752.9	4.85
Error	474	4181403.1	8821.5	

[a] Probability values are reported for each of the three possible sources of variability. Values reported include the degrees of freedom (df), sum of squares (SS), mean squares (MS), and the F-value.
[b] Fiber combination, $P = 0.01$.
[c] Foot, $P = 0.19$.
[d] Fiber combination × foot, $P = 0.002$.

ning gait.[2,5,8,20,22] Coaches, athletic trainers, and health professionals have long suggested that shearing forces, moisture, and temperature are three of the primary extrinsic factors leading to blistering.[3,4,10,13,14,17] Frequently, the sock is the material nearest the skin surface in a running shoe, and it may exert a significant influence over the potential for blistering. Thus, sock fiber superiority can be defined by its ability to reduce shear forces, reduce moisture from the surface of the skin, and reduce heat near the skin surface.

Naylor,[15,16,19] Sulzberger et al,[17] and Cortese[12] provide experimental evidence that associates shearing forces with friction blisters. Spence and Shields[18,31] and Brodsky et al[32] provide evidence that suggests that the influence of these forces on the skin may be reduced by sandwiching a closed-cellular neoprene insole between the plantar skin and the shoe insole. While it would be tempting to speculate on the shear-reducing role of a sock and its associated fibers, the experimental design applied in this study does not isolate, measure, nor evaluate the necessary parameters. On extensive review of the literature, it is apparent that no scientific evidence to date has been gathered to identify the response of a sock or its fibers to the shearing forces associated with blisters.

Moisture-laden natural fibers, such as cotton and wool, compress more easily than acrylic fibers.[24] Thus, bulk (sock intricacies), cushion, and softness are reduced. Cotton socks have been reported to lose as much as 42% of the initial dry thickness, while acrylic socks under the same conditions lost only 32% of their initial dry thickness.[24]

Silverman and Powell,[33] after investigating the sweating of 1,100 Army patients, reported that a moist sole creates a dynamic adhesion between the sole and the supporting surface at the moment of propulsion. More recent experimental investigations provide additional details that further suggest that intermediate degrees of moisture on the skin interface will tend to increase friction,[15-17,19,34,35] while extreme dryness and wetness will tend to decrease friction.[17] Prolonged wetness of the skin interface will lead to maceration of the outer stratum corneum. A macerated stratum corneum, especially when macerated by an alkaline perspiration, loses the ability to function effectively as a protective barrier, and injury is more likely.[36-38]

Naylor[19] proposed hypotheses to explain the response of the skin to the effects of oil and excess water, damp or trace water, and a dry surface. Excess water may act to form a hydrodynamic or fluid lubrication layer, which effectively reduces shear forces.[19] On the other hand, a damp skin surface may act to increase the frictional coefficient by impeding the dynamic shear-absorbing properties of dry skin.[19] The influences of shearing forces on the epidermis are reduced on dry skin secondary to exfoliation of keratinocytes and cellular debris from the outermost stratum corneum, much as graphite might protect a metallic surface. Thus, a dynamic shear-absorbing interface forms in response to frictional forces, providing limited protection to the deeper layers of the epidermis. Naylor[19] refers to this dynamic shear-absorbing property as a dry lubricant.

Cotton and wool absorb moisture nearly 2 times more than acrylic during athletic activity.[24] In addition, cotton and wool exhibit the ability to retain moisture 10 times more than acrylic.[24] In the authors' opinion, this ability to retain moisture may be attributed to swollen, moisture-laden fibers that fill the air spaces in the sock interstices, thus trapping significant quantities of moisture. Current knitting industry documents provide detailed measurements regarding the "swellibility of fibers."[39] These documents state that acrylic fibers will swell less than 5%, while cotton fibers swell 44% to 49% and wool fibers swell 32% to 38%.

The transport of moisture from the surface of the foot to the outside environment is called wicking. In this context, it is defined as the movement of perspiration from the foot surface through the sock and shoe upper (Fig. 2). Wicking is thus limited only by the ability of the sock and shoe materials to effectively transport the perspiration. The mechanics of effective wicking must take into account the movement of moisture on the surface of the sock fibers in the air spaces and interstices between the fibers. In effect, the moisture is moving by capillary action and may be aided by a mechanical force generated by pressure of the foot against the sock with each step in the stance phase of gait.

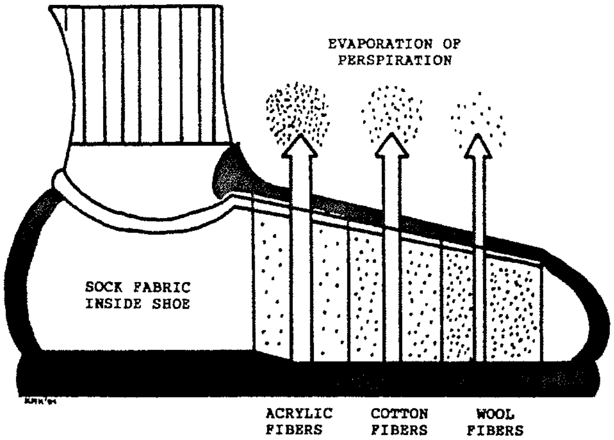

Figure 2. A diagrammatic representation of wicking through three different sock fibers and the running shoe upper. As can be noted from this diagram, acrylic fibers can help promote wicking, thus transporting more perspiration from the surface of the foot.

Cotton has a higher resistance to sweat transport. When it becomes wet, the fibers swell and the sock compresses easily. In this manner, a compact resistive barrier is formed, further preventing sweat transport. When water flow-through properties of acrylic *versus* cotton have been tested, it has been noted that cotton exhibits a 2.4 times higher resistance to moisture transport.[40] Thus, a cotton sock may, in fact, compromise the movement of excess moisture from the surface of the foot, while an acrylic sock may augment the movement of moisture from the surface of the foot.[41]

Temperature has been identified as a contributing factor associated with the formation of friction blisters.[3, 4, 6, 10, 12–14, 16, 17, 19] In a search of the literature, no scientific reports were found to provide support for this general concept. The authors' results suggest that when heterogeneous sock combinations, ie, cotton *versus* acrylic, were worn, runners were able to detect a significant difference. However, when all cotton and acrylic runs were combined, the results suggest that the runners were unable to detect a significant temperature difference.

Conclusion

For a group of N = 35 runners completing over 890 run replicates the following conclusions can be made.

Major Points. Acrylic socks were associated with a significant reduction in the occurrence of friction blisters when compared directly to cotton fiber socks. Acrylic fiber socks were associated with a significantly smaller blister size (mm^2) when compared to cotton fiber socks. Under these test conditions and using the test socks, severe blistering of the foot associated with running activities is an uncommon event.

Minor Points. For the sock characteristics of padding and sock-shoe adhesions, runners were unable to detect any significant difference between acrylic fiber socks and cotton fiber socks. Acrylic fiber socks were associated with the perception of a significantly drier sock and drier foot when compared to cotton fiber socks. Acrylic fiber socks were generally associated with the perception of a warmer foot during running.

It is the opinion of the authors that, based upon these results and conclusions, coaches, athletic trainers, and health professionals should reconsider the role of acrylic sock fibers for the prevention of friction blisters. It must also be recognized that the socks used in this research were produced by using a unique patented sock construction, and that this particular sock design may pose either a contributory or preventive effect.

The results presented here are from the first of a three-part study that will attempt to shed additional light on the influence of sock fibers and construction on friction blisters.

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