Comparison of Cotton and Acrylic Socks Using a Generic Cushion Sole Design for Runners

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A longitudinal single-blind study was conducted to test the friction blister prevention properties of synthetic acrylic socks in a generic construction. This study serves as a comparison with the authors' previous work comparing acrylic and cotton socks in a patented padded construction. Twenty-seven long-distance runners provided data regarding dampness, temperature, friction blister incidence, severity, and size. Two different socks were tested; each was identical in every aspect of construction except the fiber content. One test sock was composed of 100% synthetic acrylic fibers, and the other was composed of 100% natural cotton fibers. These results were unsuccessful at demonstrating any superiority of cotton or acrylic fibers when knitting produced a generic "cushion sole" sock. The superiority of acrylic fibers has thus far been demonstrated only when sock knitting provides adequate anatomical padding.

Recommendations regarding the selection of the most appropriate athletic sock continues to be debated, with reliance on personal biases, convenience, and anecdotal evidence.[1, 2] Unfortunately there continues to be only limited experimental evidence available regarding the selection of the most appropriate sock fiber composition or sock design.[3-5] Recent work by Veves et al[6, 7] revealed a profound ability of a uniquely padded sock to dissipate abnormal plantar pressures in the feet of diabetic patients with neuropathy. In addition, these same densely padded socks have demonstrated the ability to reduce pain by 50% in the feet of patients with rheumatoid arthritis.[8] Clearly, the protective role provided by socks has been greatly underestimated.

Blistering of the feet, resulting from an intraepidermal injury, is frequently encountered during running activities.[9-13] At a recent western US ultra-endurance event, it was observed that six out of every ten participants sought attention for painful pedal blistering injuries (personal observations and data from the 1992 Angeles Crest 100 Mile Endurance Run, CA, K.M. Herring, 1992). Typically an insignificant injury, blistering can compromise the performance and health of an athlete.[14-19] Thus, considerable interest and attention have been directed at the development, physiologic and histologic changes, and prevention and treatment of these common cutaneous injuries.[4, 5, 20-40]

Several factors have been associated with the development of friction blisters. These include ill-fitting and worn-out shoes, ill-fitting, worn-out, and wrinkled socks, dynamic shearing forces, and moisture on the surface of the foot.[2, 5, 11, 13, 22, 32, 34, 36, 39, 41] Only recently has fiber content or construction of socks been questioned. Herring and Richie[3] reported the results of a double-blind study that observed fewer, smaller, and less severe pedal blistering events among runners using a special patented padded construction of acrylic socks when compared with cotton fiber socks of an identical construction. The authors were unable to determine if the superiority of acrylic fibers demonstrated in this study was caused by the fiber composition or the unique dense padding used in the experimental socks. Thus, a second, longitudinal, single-blind study was undertaken to test the conclusions of

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Herring and Richie[3] using a generic 108 needle cushion sole sock design.

Materials and Methods

This investigation applied the experimental design and sock fiber content of a study conducted by Herring and Richie.[3] The study parameter for sock construction was altered. A generic 108 needle cushion sole sock design was applied for the purposes of comparison.

Project Participants. Fifty runners from the Los Angeles and San Francisco, areas participated in this study. These runners represent a broad cross section of recreational long-distance runners. Factors taken into consideration included experience, frequency of training, lower extremity biomechanics, and history of previous blistering. Criteria for participation and subsequent elimination were consistent with previous experimental design described by Herring and Richie.[3] Runners participating in the previous study were offered an opportunity to participate in this study. Additional participants were recruited from local running clubs. Subsequent elimination of potential participants was based on abnormal biomechanics of the foot and ankle, and a dermatologic examination. Before data collection, each runner participant was provided with specific instructions regarding accurate data collection, care and laundering of the test socks, and running limitations.

Sock Description. Each runner participant was issued three pairs of 108 needle 18-gauge cushion sole acrylic and cotton socks. The fibers used to knit the cotton socks included 20/2's 100% combed cotton with 2/70's stretch nylon used for elasticity. A finished cross stretch of 9¾ inches in the top, and 7¾ inches in the foot, and 16 inches in foot length was applied. The fibers used to knit the acrylic socks included 2/30's type 42 acrylic with 2/70's stretch nylon used for elasticity. A finished cross stretch of 9¾ inches in the top, 7¾ inches in the foot, and 16 inches in foot length was also applied. The finished sock sizing at dispensation to the runners was within ± ⅛ inch in cross stretches and ± ¼ inch in foot length. The finished cotton socks were distinguished from acrylic socks by the presence of a single yellow mark applied to the outer sole of the cotton socks. This mark was used solely for the purposes of sock identification. Every effort possible 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 were collected from a series of four experimental and control test sock pairings. Each test pairing represented a unique sock combination: A, control, right foot cotton and left foot cotton; B, control, right foot acrylic and left foot acrylic; C, experimental, right foot acrylic and left foot cotton; and D, experimental, right foot cotton and left foot acrylic.

The homogeneous or control groups of all cotton or all acrylic socks were used to establish differences in sampling data attributable to right foot *versus* left foot. Heterogenous or experimental cotton and acrylic fiber combinations were used to observe differences in sampling data attributable to sock fiber content.

Each test pairing corresponded to a series of ten run-trial efforts conducted over a 10- to 30-day period. The basic data collecting unit was called a run. Once the runners began a run-trial series for a specific sock combination, they would continue with that series of runs until they had completed the required ten replicates. Only at this time could a new run-trial series and sock combination be started.

Runners were instructed to complete runs of between 45 min and 180 min. Before run preparations, and before and after run documentation and responses to blistering were consistent with the experimental design described by Herring and Richie.[3] 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 dispensation. Numerous other variables exist; of these, age, gender, weight, body type, and running gait were not controlled.

Friction Blister Evaluation. At the conclusion of each run-trial, the runners examined both feet and socks. Both examinations were consistent with those described by Herring and Richie.[3] This included observations regarding sock protection, dampness, and temperature characteristics unique to the run-trial. Observations were entered as individual run-trial records.

Foot examinations after the run-trial focused on changes or observations related to the skin and nails. Skin irritation and injury were carefully identified by anatomical area, measured (greatest dimensions, length *versus* width), and scored with regard to the severity of the injury. The scoring scale used to rate the severity of friction blisters is as follows: grade 1, no postrun redness and no pain (a blister "hot spot"); grade 2, postrun redness and no pain; grade 3, postrun redness, loose surface skin and pain; grade 4, postrun redness, an elevated and fluid-filled pocket of surface skin and pain; and grade 5, postrun redness, broken surface skin, or an elevated and blood filled pocket of surface skin and pain.[3]

Data Analysis. In light of the nature of the data collected, both parametric and nonparametric data analyses were applied. Where appropriate, data transformations were performed to assist in the normalization of these data before any statistical test was applied. The manipulation of the data was accomplished with SYSTAT®[1], a system for statistics, and a personal computer.

Results

A total of $N = 50$ runners participated in this study. Of this group, 23 runners terminated data collection for a variety of reasons including loss of socks, loss of data, loss of interest, illness, and injury. Twenty-seven runners satisfactorily completed the necessary replicates for all four sock combinations. This group is subsequently referred to as the study group or sample population. Included were 18 males and nine females. Table 1 provides a demographic profile of these runners. All incomplete records were treated as missing data and not assigned a numeric value or rank score.

The mean duration for all run-trials was calculated to be 60.9 min. A minimum mean run-trial duration of 60.3 min was observed for sock combination A (left and right foot cotton) and a maximum mean run-trial duration of 62.4 min was observed for sock combination D (right foot cotton and left foot acrylic). When mean duration for individual sock combinations (A to D) was compared, no significant difference could be detected. These data, therefore, do not appear to favor any particular sock combination (A to D), on the basis of run-trial duration.

A total of $N = 149$ blisters were reported from a total of 1,016 run replicates. A total of 55.7% (83) of the blisters were associated with acrylic socks and 44.3% (66) were associated with cotton socks.

The anatomy of the foot was used to group these events. A disproportionate clustering of blistering was observed; the forefoot accounted for 53% while the midfoot and hindfoot accounted for 36.2% and 10.7% of blistering events, respectively (Table 2). This pattern of distribution is consistent with that reported in previous studies.[3] Examination of calculated blister ratios for each sock combination demonstrates a remarkable similarity (Table 3). This suggests a near equal tendency for blistering while wearing any of the test socks.

Table 1. A Demographic Profile of 27 Runners With Mean and Standard Deviation Reported for Each Category

	Mean (SD)
Age (yrs)	38.1 (9.4)
Training History	
Experience (yrs)	10.6 (6.2)
Frequency of running (days/week)	5.9 (1.1)
Distance (miles/week)	40.9 (19.7)
Pace estimate (minutes/mile)	7.8 (0.94)

Runners evaluated basic physical properties that could be directly related to the fiber composition of the socks in question (Table 4). These properties included perceived degree of sock dampness and perceived foot temperature.

Runner dampness rating values for the socks were evaluated as a frequency distribution of individual scores and Pearson χ^2 tests were applied to these data. When dampness was rated for both homogeneous and heterogeneous sock combinations, runners were unable to detect a significance difference in the extent of sock dampness after a run.

Runner temperature rating data for foot temperature were evaluated by test combination. Pearson χ^2 tests were applied to the frequency distribution generated for each data set. Homogenous sock combinations of cotton (L) *versus* cotton (R) and acrylic (L) *versus* acrylic (R) exhibited no significant difference between right and left feet. Likewise, no significant difference could be detected for temperature scores among heterogeneous sock combinations of acrylic and cotton socks.

The frequency distribution of the reported friction blisters was evaluated by anatomical area and sock combination (Tables 2 and 5). When a Pearson χ^2 test for goodness of fit was applied to these data, no significant difference could be detected among the four sock combinations. In general, a runner was equally likely to develop a friction blister while wearing either cotton, acrylic, or mixed sock combinations.

Blister severity was evaluated on a scale of 1 to 5 as described by Herring and Richie.[3] The resulting frequency distribution of blister severity and sock fiber content did not exhibit any distinct patterns of distribution (Table 6). A Pearson χ^2 test for goodness of fit was performed on this distribution of pooled data. The results suggest that the observed distribution of blister severity did not significantly differ from the expected blister severity calculated for these data (Pearson $\chi^2 = 3.427$; df = 3; P = 0.489).

Independently, severity was examined for each sock combination. Again, the Pearson χ^2 test for

®[1]SYSTAT, Inc, Evanston, IL.

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

	Sock Combination			
	Acrylic (R) Acrylic (L) (N = 262)	Cotton (R) Cotton (L) (N = 258)	Acrylic (R) Cotton (L) (N = 254)	Cotton (R) Acrylic (L) (N = 242)
Number of blisters	46	29	35	39
Right forefoot	16	9	7	12
Left forefoot	12	7	6	10
Right midfoot	11	6	10	6
Left midfoot	5	4	8	4
Right rearfoot	2	2	3	4
Left rearfoot	0	1	1	3
Right foot total	29	17	20	22
Left foot total	17	12	15	17

[a]*N*, number of replicates.

Table 3. Summary of Blistering Tendency for All Runs, With Separate Results for Each Sock Combination[a]

	Measures of Blistering Tendency			
Sock Combination	N = Runs	N' = Blisters	Blister Ratio	Mean Blister Size (mm²)
Cotton (R)	258	17	0.066	122.5
Cotton (L)	258	12	0.047	35.5
Acrylic (R)	262	29	0.111	153
Acrylic (L)	262	17	0.065	50
Acrylic (R)	248	20	0.081	66.2
Cotton (L)	248	15	0.06	90.6
Cotton (R)	242	22	0.091	71.7
Acrylic (L)	242	17	0.07	63.0
Cotton fibers	1,006	66	0.066	80.1
Acrylic fibers	1,014	83	0.082	83.0

[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.

Table 4. Summary of Sock Characteristics for All Individual Run-Trials[a]

		Rating Scale		
Sock Combination	N	Dampness to Feet (SD)	Dampness to Socks (SD)	Temperature to Feet (SD)
Cotton (R)	126	1.88 (0.83)	2.18 (0.84)	2.87 (0.56)
Cotton (L)	126	1.89 (0.84)	2.15 (0.82)	2.85 (0.54)
Acrylic (R)	130	1.86 (0.88)	1.93 (0.77)	2.87 (0.59)
Acrylic (L)	130	1.83 (0.87)	1.91 (0.76)	2.82 (0.58)
Acrylic (R)	127	2.01 (0.93)	2.13 (0.80)	2.91 (0.57)
Cotton (L)	127	1.97 (0.9)	2.21 (0.85)	2.89 (0.57)
Cotton (R)	123	1.93 (0.78)	2.24 (0.83)	2.85 (0.6)
Acrylic (L)	123	1.91 (0.84)	2.12 (0.8)	2.89 (0.67)

[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.

Table 5. Results of Pearson χ^2 Test for Goodness of Fit for the Observed Distribution of Friction Blisters Among All Sock Combinations[a]

	Sock Combination				
	Cotton (R) Cotton (L)	Acrylic (R) Acrylic (L)	Acrylic (R) Cotton (L)	Cotton (R) Acrylic (L)	Totals
Right foot					
Observed	17	29	20	22	88
Expected	14.5	23	17.5	19.5	
χ^2					3.15
Left foot					
Observed	12	17	15	17	61
Expected	14.5	23	17.5	19.5	
χ^2					1.1
Totals	29	46	35	39	149

[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) = 9.98; P = 0.1897.

Table 6. A Summary of Runner Reported Friction Blister Severity for All Sock Fiber Combinations[a]

Sock Combination	Blister Severity 1	2	3	4	5	Totals
Cotton (R)	9	3	2	0	3	17
Cotton (L)	7	2	1	2	0	12
Acrylic (R)	10	11	3	3	2	29
Acrylic (L)	3	8	3	3	0	17
Acrylic (R)	14	2	3	1	0	20
Cotton (L)	6	5	2	2	0	15
Cotton (R)	16	3	1	1	1	22
Acrylic (L)	13	3	1	0	0	17
Cotton fibers total	38	13	6	5	4	66
Acrylic fibers total	40	24	10	7	2	83

[a]*N*, 149.

goodness of fit was applied. In all cases, including homogeneous and heterogeneous sock combinations, the test statistic was not significant. Clearly, based on the fiber content of the sock tested, severity of blistering could not be predicted.

The blister area size in mm² was initially pooled for evaluation. Clearly, the raw data were highly variable (Table 3). This may represent a skewing of the data based on the anatomical site of the blister being measured. Thus, all area data underwent a natural logarithm transformation. From the resulting transformed data, mean and standard deviations were calculated for acrylic fiber socks (mean = 3.814 ± 1.260) and cotton fiber socks (mean = 3.931 ± 1.114). An independent samples *t*-test was then imposed on the log-area data grouped by sock fiber. The result of this test statistic suggested that no significant difference existed between acrylic and cotton fiber socks in regard to blister area (Table 7). Clearly, the area of a blister could not be predicted based on the fiber content of the sock worn.

Table 7. Summary of Pooled Log-Area Data for Blisters Reported by Runners[a]

Group	*N*	Mean	SD
Acrylic	83	3.814	1.260
Cotton	66	3.931	1.114

[a]Separated variances of T = 0.598, df = 145.3, P = 0.551.

Nonpooled data for runner-reported blister area were examined. Again, the data underwent a natural logarithm transformation. The resulting log-area was then used for all subsequent tests for statistical significance. Independent *t*-tests were performed on each of the sock combinations.

When homogeneous sock combinations were tested in this manner, the results were significant (acrylic (L) *versus* acrylic (R), P = 0.01; cotton (L) *versus* cotton (R), P = 0.000). This result may, in part, be explained by the frequency distribution of the blisters. This distribution appeared to be influenced by the anatomical location of the reported blisters.

Heterogeneous sock combinations were subjected to an identical level of scrutiny. Test statistic values clearly suggest that no significant difference could be identified in blister log-area when data were grouped by sock fiber cotton (R) *versus* acrylic (L), P = 0.329; acrylic (R) *versus* cotton (L), P = 0.663. Clearly from these data, no accurate prediction can be made concerning blister size based on sock fiber content.

Discussion

The authors previously reported the results of a double-blind study comparing socks composed of 100% natural cotton fibers *versus* 100% synthetic acrylic fibers in a unique patented padded construction.[3] In this previous study, the test subjects were able to detect significant differences between the two sock fiber types (acrylic *versus* cotton) for the categories of temperature, dampness, blister size, blister severity, and total number of blistering events.[3] In this regard, acrylic fiber socks were associated with reduced dampness to the foot, slightly increased temperature, reduced blister size, and reduced severity and number of blistering events.[3] Thus, the authors cautiously concluded that the differences found between the two socks were caused by fiber composition.

In this study, no significant difference could be detected between cotton *versus* acrylic fiber socks when a more generic 108 needle cushion sole construction was applied. Although the number of test subjects was reduced in this study (35 runners *versus* 27 runners), there appears to be no plausible explanation from an experimental design standpoint to explain the marked difference between the two studies. Sock construction representing density and anatomical placement of padding marks the only significant deviation this study makes from the experimental protocol applied in the previous study. Thus, the superiority of acrylic fibers over cotton, as demonstrated in the earlier study, must now be qualified.

Numerous laboratory studies have pointed to the potential superiority of acrylic fibers used in the construction of socks for vigorous athletic activities.[42, 43] These studies have demonstrated that, compared with cotton, acrylic fibers will compact less easily, retain their shape, swell less, and wick moisture from the surface of the foot. The present study suggests that the acrylic fibers must be constructed in a dense framework of material with ample interstitial space to allow the superior physical properties of acrylic fibers to be enhanced.

The formation of a blister is a response of the skin to a shearing force that exceeds the intrinsic pliability of the epidermis and results in the formation of a fluid-filled cleft.[39] While shearing forces occur during normal walking, running greatly intensifies their action. To reduce potentially damaging shearing forces, a protective material must be interfaced between the skin and the running surface. To be most effective, this material must demonstrate unique physical properties, including the ability to absorb shearing energy and direct movement away from the intraepidermal framework of the skin. Shearing forces can be dissipated through the shoe outsole-running surface interface. Within the shoe, multiple interfaces coexist (insole-shoe, sock-insole, foot-sock), each with the potential to dissipate or exacerbate shearing force.

The authors' experimental work indicates that for a sock to dissipate moisture and shearing forces, it must have sufficient density of padding to allow internal movement of the fiber framework of the sock itself. Thus, by allowing movement to occur within the sock interstices, shearing movement is reduced at the sock-skin interface. This is similar to the shearing force dissipation concept proposed by Spence and Shields[32, 36] in describing shear-reducing insoles for athletic footwear or the multilayer sock combination proposed by Akers[5] for reducing the tendency of blistering.

Moisture (perspiration) is a significant secondary factor contributing to blistering on the feet of humans. Moisture at the skin surface inversely affects the measurable coefficient of friction at the skin surface.[22] Several authors have shown that either totally dry or extremely wet skin will exhibit low coefficients of friction.[20-22, 24, 41] Intermediate levels of moisture will significantly increase the coefficient of friction at the skin surface.[22, 24]

In order for a sock to provide an optimal moisture environment and prevent blisters, the sock should either maintain a minimal quantity of moisture on the skin surface or an extremely large quantity of moisture. A sock could help deliver a greater quantity of moisture at the skin surface if it provided an occlusive impervious barrier to water transport, therefore allowing perspiration to accumulate at a steady-state rate along the skin surface. The skin of the foot could literally glide along on a thin surface of moisture against the sock interface. Such a system appears impractical and potentially quite uncomfortable to the athlete. The alternative situation of providing a dry surface for the foot appears more realistic. A sock can reduce moisture against the surface of the skin by absorbing moisture from the skin surface, or by wicking moisture from the surface and moving the moisture through the fiber framework of the sock to the shoe upper.

Natural fibers such as cotton and wool have excellent moisture absorption properties, but exhibit poor wicking potential.[42] The converse is true for synthetic acrylic fibers, which exhibit poor moisture absorption and excellent wicking potential.[43] During vigorous physical activity, the moisture production by perspiration on the surface of the human foot far exceeds the ability of any sock to fully absorb the moisture produced.[44] Therefore, if a dry environment is to be maintained at the skin surface, an effective wicking process must occur that would actually transport moisture from the skin surface and deliver it to the shoe upper for potential evaporation.

A generic cushion sole construction sock, as tested in this study, may reduce the effectiveness of wicking by the acrylic fibers compared with the previously tested, densely padded, patented socks.[3] Wicking is limited by the resistance to sweat transport, sock compaction, sock flow-through properties, and the extent of air spaces and interstices between the sock fibers. A thinner sock will have reduced air space and interstices and reach maximum compaction more rapidly. Reduced air spaces with a smaller framework of fiber interstices will reduce the immediate reservoir effect of the sock. Thus, perspiration from the skin surface will rapidly fill the available space. Because of the slower transfer of moisture from the sock to the shoe upper, the moisture turnover rate within these spaces will be decreased, thus slowing the uptake of new moisture produced at the skin surface. The net effect would be an increased or more "intermediate" level of moisture at the skin-sock interface that has been shown by previous investigators to greatly increase the propensity for the formation of friction blister lesions.[24, 25]

In summary, the thinner, generic cushion sole sock construction does not appear to be dense enough to form an effective framework of dense padding to dissipate shearing forces. The compaction of the fibers within the sock minimizes the chance of the sock to provide an effective shearing force dissipation mechanism. This compaction may also compromise the wicking of moisture away from the skin surface.

Conclusion

A generic cushion sole sock construction was used to compare acrylic *versus* cotton fibers in a longitudinal study on 27 long-distance runners. This sock construction failed to show any superiority of cotton or acrylic fibers in terms of temperature, moisture, or friction blisters.

These findings differ from the authors' previous investigation comparing cotton *versus* acrylic fibers in a special, densely padded, patented sock construction. The denser padded sock appears to enhance the effectiveness of acrylic fibers compared with cotton by providing a thicker anatomically distributed framework of material to dissipate shearing forces and an effective interstitial framework to enhance the wicking mechanism and provide optimal moisture environment on the pedal skin surface.

If coaches, athletic trainers, and health professionals are to recommend acrylic fiber socks for active people, clarification should be made that acrylic fiber socks must be constructed with dense padding to enhance the physical properties of the fibers.

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