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The cushioning properties of athletic socks: An impact testing perspective

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ABSTRACT

Background: One of the aims of the sock/shoe unit is to reduce the severity of impact forces on the lower extremity although the injury prevention potential of the sock through the attenuation of impact force has yet to be established. This study aims to determine the effect of athletic socks and a sock/shoe unit on peak impact force, time to peak impact force and loading rate using an impact testing methodology.

Methods: An impact testing system with a gravity driven vertical impact striker (8.5 kg) fitted with a load cell (10,000 Hz) which was released from 0.05 m to impact the specimen on the vertical axis (impact velocity $= 0.99\ \text{m}\cdot\text{s}^{-1}$) was used throughout the study.

Findings: All socks reduced peak impact force by between 6% and 20% when compared to a no sock control condition. Furthermore, large significant correlation coefficients ($r = .62$ to $.72$) were observed between thickness and peak impact force, time to peak impact force and loading rate in the sock only condition.

Interpretation: Athletic socks demonstrate cushioning properties under impact testing conditions.

1. Introduction

Previously considered a commodity item, the athletic sock has since been subjected to much biomechanical research with a specific focus on pressure reduction (Blackwell et al., 2002; Flot et al., 1995; Garrow et al., 2005; Veves et al., 1989, 1990, 1992). However, limited research exists regarding the cushioning properties of athletic socks. The sock/shoe complex aims to reduce moisture, blister formation (Dai et al., 2007) and the severity of impact forces (Howarth and Rome, 1996), yet the injury prevention potential of the sock through the attenuation of impact force has yet to be fully established.

Early research investigating socks assessed specially designed padded socks utilising optical pedobarography to determine whether socks could relieve abnormally high plantar pressures in patients suffering from peripheral neuropathy (Veves et al., 1989, 1990) and rheumatoid arthritis (Veves et al., 1992) when walking. Significant reductions in peak forefoot pressure (Veves et al., 1989, 1990) and total foot pressure (Veves et al., 1992) were observed in experimental socks when compared to barefoot walking. Furthermore, commercially available sports socks of high and medium density significantly reduced plantar pressure by 17% and 10% respectively when compared to barefoot walking, although these pressure reductions were not as great as that seen in the experimental socks (27%). When assessing padded socks with the inclusion of extra depth shoes, Flot et al. (1995) reported significant reductions in forefoot pressures when compared to a control sock, although these findings were not uniform and were limited to the hallux and central forefoot regions.

More recently, in participants exhibiting moderate to severe signs of peripheral neuropathy, multi-layered socks significantly reduced both in-shoe total foot pressure (9%) and peak forefoot pressure (14%) when walking. These reductions were attributed to an 8% increase in contact area when wearing the multi-layered socks (Garrow et al., 2005).

Conversely, in diabetic participants, a diabetic sock (100% cotton) was not effective at reducing in-shoe plantar pressures (Blackwell et al., 2002). However, the material configuration of the diabetic sock (100% cotton) was of similar composition to the designated 'control' socks in previous studies. Cotton socks have a thin material construction and lack natural elasticity and resilience (Howarth and Rome, 1996). The findings of this study are therefore in accordance with previous literature, in such that socks composed of 100% cotton do not reduce plantar pressures when walking (Flot et al., 1995).

Although the findings of these studies are valuable, the use of participants suffering from neuropathy (Garrow et al., 2005; Veves et al., 1989), rheumatoid arthritis (Veves et al., 1992), and diabetes (Blackwell et al., 2002; Veves et al., 1990) and the use of extra depth footwear (Flot et al., 1995) to accommodate padded socks mean that they may not be applicable to an athletic population.

Howarth and Rome (1996) investigated the effects of socks on shock attenuation over 72 h. Utilising a shock meter (ankle mounted piezoelectric accelerometer), significant reductions in shock meter

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readings were observed in a wool cushion and an acrylic cushion sole sock when compared to barefoot walking (Howarth and Rome, 1996). To avoid confounding variables, this study negated the use of footwear, however this reduces the ecological validity of the data reducing its application (Stiles and Dixon, 2007).

A combination of a force plate and infrared cameras have been used to analyse the kinetic and lower limb kinematic variables associated with running in commercially available cotton running socks (Schwellnus et al., 2005). However, limited information is available about the findings as they were presented in a conference abstract. Nevertheless, Schwellnus et al. (2005) concluded that the vertical impact force, horizontal breaking force, knee flexion and extension angles and ankle plantar dorsi-flexion angles were unchanged when running in a commercially available cotton running sock compared to a no sock condition. However, based on previous literature it is proposed that socks composed primarily of cotton, lack the natural elasticity and resilience to significantly affect both the vertical and horizontal ground reaction forces during running (Blackwell et al., 2002; Howarth and Rome, 1996).

Not only have reductions in plantar pressures been observed between socks and barefoot walking, but differences have also been observed between socks with differing thicknesses. Thicker experimental socks reduced peak plantar pressures by 35% when compared to the participants' own socks (Veves et al., 1989) and by 22% (Veves et al., 1990) and 15% when compared to other socks of medium thickness (Veves et al., 1992). In addition, padded socks significantly decreased plantar pressures by 16% in the hallux region of the foot when compared to a non-padded control stocking (Flot et al., 1995). These findings suggest that pressure attenuation may be related to the thickness of the sock.

Previous research focussing on socks has been participant-based. Although these methods are representative of real-life situations, it is difficult to determine whether the significant findings can be solely attributed to the sock alone rather than to confounding variables such as changes in lower extremity kinematics. Moreover, tests with subjects can be time consuming and have more inter-subject variability than inter-shoe variability (Chiu and Shiang, 2007) and possibly inter-sock variability. Additionally, in these studies only a small number of socks had been incorporated when other socks may have been more effective at attenuating shock. Furthermore, in some cases, previous research (Blackmore et al., 2011; Howarth and Rome, 1996) has negated the use of footwear to limit confounding variables, however, this approach reduces the ecological validity of the findings and does not assess the cushioning properties of the sock/shoe unit. Moreover, during high impact conditions, it has been reported that the absorption qualities of an insole were masked by the greater absorption qualities of a shoe sole (Chiu, 2005) which may also happen to the sock. To combat these factors, an impact testing device has been suggested to show the cushioning properties of shoe soles quickly (Chiu and Shiang, 2007) and the reliability of such a system has been determined when assessing athletic socks (Blackmore et al., in press). The use of such a system will enable the testing of a range of socks to determine the cushioning properties of each sock, as well as assessing the cushioning properties of the sock/shoe unit.

Impact testing has often been used to assess the cushioning property of footwear (Hennig et al., 1993; House et al., 2004; McCaw et al., 2000; McNair and Marshall, 1994; Milani et al., 1997), insoles (House et al., 2002, 2004) and other surface materials (Stiles and Dixon, 2007), although it has yet to be used to determine the cushioning properties of athletic socks. To ensure a consistent approach, the impact testing methodology in the current study will be based on a standard devised by the American Society for Testing and Materials (1999). The aim of this was to simulate peak compressive forces comparable to that experienced by a shoe mid-sole in heel strike tests for normal running movements (American Society for Testing and Materials, 1999; Denoth, 1986; Misevich and Cavanagh, 1984). In previous impact testing studies, a reduction in peak impact force or peak 'g' has been deemed an indicator of attenuation when compared to other materials or conditions (Chiu, 2005; Chiu and Shiang, 2007; Hennig and Lafortune, 1991; House et al., 2004; McNair and Marshall, 1994; Stiles and Dixon, 2007). The duration to peak impact force or loading rate has not been considered in previous impact testing literature, although these variables have been assessed in previous studies in this area using a force platform (Blackmore et al., 2011) and may allow a comparison between results from the current study and previous research. In addition, analysis of these variables may provide a valuable insight into the performance of the materials under impact testing conditions. Therefore, the current study will utilise an impact testing methodology and aim to determine the effect of athletic socks and a sock/shoe unit on peak impact force, time to peak impact force and loading rate. Firstly, it is hypothesised that athletic socks will decrease peak impact force and loading rate while increasing the time to peak impact force. Secondly, it is hypothesised that socks with a greater thickness will be more effective at attenuating impact forces.

2. Methods

2.1. Conditions

The study consisted of nine sock conditions (eight socks and a no sock control; Table 1) and nine sock and shoe conditions (a combination of a shoe and the socks outlined in Table 1, plus a shoe only control). Sock thickness was measured using Digital Vernier callipers (S0707, Sealey, Colchester, England) at the area of maximum thickness on the plantar aspect of the sock. A new sock was used for each trial and to avoid confounding variables such as specimen thickness the same shoe (Fig. 1) was used throughout the study. It has been suggested that the use of a modern shoe can complicate the interpretation of impact mechanics (Stiles and Dixon, 2007) and

Table 1

Details and material configuration of each condition (ranked by thickness).

Condition	Sock name	Thickness (mm)	Material configuration
No sock	No sock	0.0	No sock
Shoe	Shoe	9.7	Laced canvas upper and vulcanised rubber sole
Sock 1	Off road anklet	4.5	49% Merino wool, 47% nylon, 4% LYCRA® Sport
Sock 2	Padded plus	4.4	Inner sock: 80% Thermocool® (polyester), 20% nylon; outer sock: 50% Thermocool® (polyester), 42% nylon, 6% elastane, 2% LYCRA® Sport
Sock 3	Sport anklet	3.2	50% CoolMAX® (polyester), 47% nylon, 3% LYCRA® Sport
Sock 4	Marathon fresh anklet	3.4	40% Merino wool, 57% nylon, 3% LYCRA® Sport
Sock 5	Trail anklet	3.2	47% polypropylene, 22% cotton, 16% nylon, 10% elastane, 4% X-Static®, 1% LYCRA® Sport
Sock 6	Lite plus anklet	2.9	37% Tactel®, 10% BodyFresh (nylon), 49% nylon, 4% LYCRA® Sport
Sock 7	Socklet	2.0	Inner sock: 100% Meryl® SkinlifE Tactel®; outer sock: 40% cotton, 26% polyester, 18% nylon, 14% elastane, 2% LYCRA® Sport
Sock 8	Lite anklet	1.4	96% Tactel®, 4% LYCRA® Sport

Note: Socks 1–8 were tested in conjunction with the shoe. Tactel is a form of nylon.

Fig. 1. Basic shoe (Newitts, York, England) with laced canvas upper and vulcanised rubber sole (e.g. plimsoll).

therefore a basic shoe was incorporated into the study. A basic shoe bridges the gap between a no shoe and a modern shoe condition ensuring that an element of ecological validity is maintained throughout the study. The basic shoe lacked arch support and heel cup depression and the midsole was composed of a vulcanised rubber sole. The shoe has been deemed durable in previous work (Blackmore et al., in press).

A power analysis (Jones et al., 2003; Whitley and Ball, 2002) based on means and standard deviations from a previous article investigating footwear (Chiu and Shiang, 1999) determined that five samples (sample = one sock or one sock combined with a shoe) for each condition will provide a statistical power of 0.8 with a 95% confidence interval.

2.2. Equipment

An impact testing system (Southampton Solent University, Southampton, UK; Fig. 2) was specifically designed and validated (Blackmore et al., in press) in accordance with many of the ASTM guidelines (American Society for Testing and Materials, 1999) to impact the athletic sock and basic shoe.

The impact testing system utilised a gravity driven vertical impact striker (8.5 kg) released from a 0.05 m height to impact the socks or sock/shoe on the vertical axis. A Kistler load cell (Kistler 9301B, Kistler Instrument AG, Switzerland) sampling at 10,000 Hz using Bioware software (version 3.24, Kistler Instrument AG, Winterthur, Switzerland) was integrated into the impact testing system between the mass and the impact head. The impact velocity of the vertical impact striker was determined in a previous study (0.99 $\mathrm{m \cdot s^{-1}}$) (Blackmore et al., in press). The impact testing system demonstrated excellent reliability (coefficient of variation <5% adjusted for 95% confidence limits) for peak impact force, with no evidence of systematic bias. Good reliability (coefficient of variation <10% adjusted for 68% confidence limits) was reported for time to peak impact force and loading rate (Blackmore et al., in press).

2.3. Procedure

The shoe and the socks were separately conditioned using 25 pre-impacts prior to testing (American Society for Testing and Materials, 1999; Blackmore et al., in press; Misevich and Cavanagh, 1984), followed by 10 recorded impacts. Subsequently, a combination of each condition (sock 1 & shoe; sock 2 & shoe) was also subjected to 25 pre-impacts followed by 10 recorded impacts.

2.4. Data analysis

MATLAB (version 7.6.0.324, R2008a, Mathworks, Cambridge, England) was used to calculate peak impact force, time to peak impact force and loading rate (the time derivative of the force–time function). To account for variability of the background noise, the mean noise level for the first 1000 samples (0.1 s) was subtracted from the peak impact force in each trial. Loading rate was calculated from the onset of force production (greater than the background noise level) to the peak impact force. The mean and standard deviations were calculated for all recorded impacts (n = 180) and for each condition (n = 18). As the focus was the magnitude of the peak impact force, the data were not filtered or smoothed.

2.5. Statistical analysis

Statistical analysis was undertaken using Predictive Analytics Software statistics version 18 SPSS Inc, Chicago, USA. Normality was determined by Kolmogorov–Smirnov tests of normality. The majority of data for each dependant variable in all conditions were normally distributed and were determined to be parametric except for the time to peak impact force in the sock condition. Sphericity was assessed using Mauchly's test and where assumptions of sphericity were violated Greenhouse–Geisser correctional estimates were implemented.

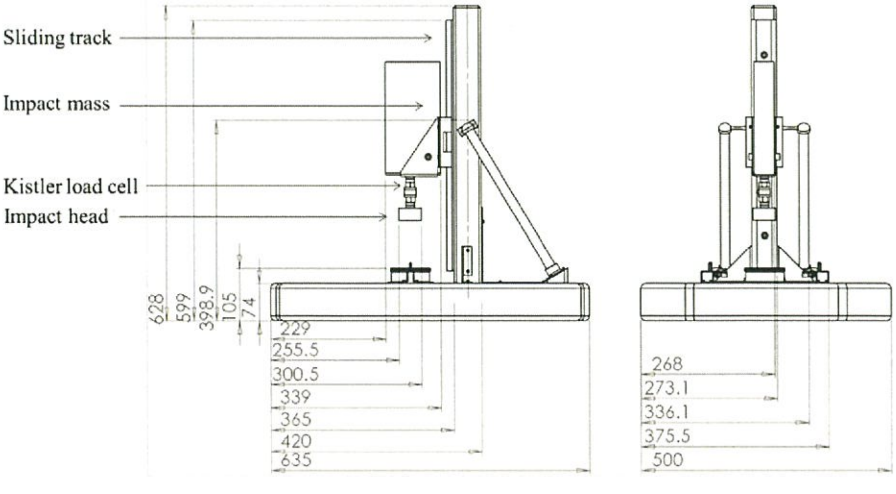

Fig. 2. Technical drawing of gravity driven vertical impact testing system (Southampton Solent University, Southampton, UK) (units in mm).

For parametric data, a factorial repeated measures Analysis of variance (condition × nine levels) with three dependant variables (peak impact force, time to peak impact force, and loading rate) was used with a simple (first) contrast to identify significant differences between conditions with an alpha level of $P < .05$. An ANOVA was used as it is reasonably insensitive to violations of the normality assumption if the sample size is large (Norusis, 2010). For non-parametric data a Friedman test was used with multiple post hoc Wilcoxon signed ranks test with a Bonferroni adjusted alpha level of $P < .05$ to determine significant differences between conditions. Pearson's correlation coefficient with an alpha level of $P < .05$ was used to determine the relationship between sock thickness and the three dependant variables and were interpreted as follows: 0.5 or greater was considered a large effect size, 0.3–0.5 was considered a moderate effect size and 0.1–0.3 was considered a small effect size (Field, 2009).

Partial eta squared (partial η^2), and Rosenthal's (1991) method (r) were used to calculate effect sizes for parametric and non-parametric data, respectively, with outputs of 0.5 or greater considered a large effect size, 0.1–0.5 a moderate effect size and less than 0.1 a small effect size (Field, 2009).

3. Results

3.1. Peak impact force

The results showed a statistically significant difference ($F_{5.0} = 397.42$, $P = .00$, partial $\eta^2 = .78$) between sock conditions (Table 2). Significant differences ($F_{5.0} = 336.61$, $P = .00$, partial $\eta^2 = .87$) were also observed in the peak impact force between sock and shoe conditions (Table 3). Contrast analysis revealed a significant reduction ($P < .00$, $\eta^2 > .55$ to .99) in peak impact force of between 3% and 20% for all sock conditions when compared to the control condition (no sock) and significant reductions ($P < .00$, $\eta^2 = .27$ to .98) of between 2% and 14% for peak impact force in the sock and shoe conditions when compared to the control condition (shoe only). However, sock seven in the sock and shoe condition ($P = .302$, $\eta^2 = .022$) did not demonstrate any significant differences and only reduced peak impact force by 0.3%.

3.2. Time to peak impact force

The Friedman test indicated statistically significant differences ($\chi^2(8, n = 50) = 276.05$, $P < .00$) between sock conditions (Table 2). Significant differences ($F_{6.0} = 127.76$, $P = .00$, partial $\eta^2 = .72$) were also observed in the time to peak impact force between sock and shoe conditions (Table 3). Post hoc analysis of the time to peak impact force in the sock conditions revealed significant increases ($P < .00$, $r = .73$ to .88) of between 8% and 33% when compared to the control condition (no sock). Contrast analysis of the time to peak impact force in the sock and shoe conditions revealed significant increases ($P < .00$, $\omega^2 = .79$ to .96) of between 15% and 32% for all of the sock and shoe conditions.

3.3. Loading rate

The results showed a significant difference ($F_{4.9} = 315.72$, $P = .00$, partial $\eta^2 = .86$) between sock conditions (Table 2). Significant differences ($F_{2.7} = 160.478$, $P = .00$, partial $\eta^2 = .76$) were also observed in the loading rate between shoe and sock conditions (Table 3). Contrast analysis of the loading rate in the sock conditions revealed significant decreases ($P < .00$, $\eta^2 = .77$ to .99) of between 14% and 41% when compared to the control condition (no sock). Significant decreases ($P < .00$, $\eta^2 = .60$ to .97) of between 17% and 35% were also observed in the loading rate in all sock and shoe conditions.

3.4. Sock thickness

Significantly ($P < .02$) large correlation coefficients were observed between thickness and the three dependant variables in the sock only condition (Table 4). A moderate relationship was observed between thickness and the three dependant variables in the sock/shoe condition, although all correlations in the sock/shoe condition were non-significant ($P > .05$).

4. Discussion

This is the first study to determine the cushioning properties of athletic socks using an impact testing method. The findings suggest that when compared to a control condition (no sock) athletic socks significantly reduce the peak impact force and loading rate, while significantly increasing the time to peak impact force under impact testing conditions accepting hypothesis one. When tested in conjunction with a shoe and compared to a control condition (shoe only), the athletic socks also significantly reduced peak impact force in all conditions except sock seven, significantly increased the time to peak impact force and significantly reduced the loading rate in all socks under impact testing conditions, accepting hypothesis one for these socks. Finally, correlation coefficients revealed that there were significantly strong relationships between sock thickness and peak impact force, time to peak impact force and loading rate in the sock only condition thus accepting hypothesis two.

Athletic socks significantly decreased the peak impact force and the loading rate by up to 20% and 47%, respectively, and increased the time to peak impact force by up to 33% when compared to the no sock control condition during loading conditions that mimicked running. A decrease in the peak impact force is representative of athletic socks attenuating impact force, whereas an increase in the time to peak impact force is representative of athletic socks providing a greater loading period under impact testing conditions (Blackmore et al., 2011). In addition, loading rate is the time derivative of the force/time function and is therefore calculated from two variables; peak impact force and time to peak impact force, and as such, the changes in both of these variables decrease the loading rate. Furthermore, the largest decrease in peak impact force and loading rate and the largest increase in time to peak impact force were observed in

Table 2
Condition thickness and mean (Standard deviation) values for peak impact force, time to peak impact force and loading rate for sock only conditions (ranked L–R by thickness after control condition).

	Sock conditions								
	No sock	1	2	3	4	5	6	7	8
Condition thickness (mm)	0	4.5	4.4	3.2	3.4	3.2	2.9	2	1.4
Peak impact force (N)	4618	3915[a]	3714[a]	4318[a]	4460[a]	4263[a]	4376[a]	4474[a]	4357[a]
	(115)	(83)	(74)	(128)	(91)	(107)	(92)	(130)	(58)
Time to peak impact force (s)	0.0024	0.0030[a]	0.0032[a]	0.0030[a]	0.0029[a]	0.0029[a]	0.0028[a]	0.0027[a]	0.0026[a]
	(0.0001)	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0002)
Loading rate (kN/s)	1823	1216[a]	1069[a]	1347[a]	1418[a]	1468[a]	1453[a]	1569[a]	1533[a]
	(86)	(89)	(53)	(76)	(99)	(80)	(70)	(63)	(128)

[a] Indicates significance ($P < 0.05$; Bonferroni adjustment $P < .005$) when compared to the no sock control condition for that respected variable.

Table 3
Condition thickness and mean (SD) values for peak impact force, time to peak impact force and loading rate for sock and shoe conditions (ranked L–R by thickness after control condition).

	Sock and shoe conditions								
	Shoe	1	2	3	4	5	6	7	8
Condition thickness (mm)	9.7	14.2	14.1	12.9	13.1	12.9	12.6	11.7	11.1
Peak impact force (N)	1922	1693^a	1663^a	1840^a	1870^a	1755^a	1888^a	1916	1860^a
	(18)	(36)	(39)	(40)	(43)	(35)	(51)	(33)	(59)
Time to peak impact force (s)	0.0052	0.0063^a	0.0066^a	0.0069^a	0.0065^a	0.0064^a	0.0064^a	0.0063^a	0.0060^a
	(0.0002)	(0.0003)	(0.0004)	(0.0003)	(0.0004)	(0.0003)	(0.0002)	(0.0002)	(0.0003)
Loading rate (kN/s)	349	235^a	226^a	251^a	265^a	274^a	275^a	280^a	288^a
	(14)	(16)	(14)	(11)	(18)	(13)	(15)	(12)	(45)

[a] Indicates significance ($P < 0.05$; Bonferroni adjustment $P < .005$) when compared to the no sock control condition for that respected variable.

sock one which was the thickest sock (4.5 mm). Sock one was composed predominantly of Merino wool (49%). Previous research suggests that wool is one of the most resilient natural fibres (Howarth and Rome, 1996) and may provide resilience to compression forces (Blackmore et al., 2011). Therefore, the high wool content may be responsible for the large decreases observed in peak impact force and loading rate as well as increases in the time to peak impact force. These findings are similar to early research where thicker experimental socks reduced peak plantar pressures by 35% when compared to the participants' own hosiery (Veves et al., 1989) and by 22% (Veves et al., 1990) and 15% when compared to socks of a medium thickness (Veves et al., 1992), although these findings were pressure reductions and not force reductions. Furthermore, these findings (Veves et al., 1989, 1990, 1992) were established using participants whereas the findings outlined in the present study were obtained using an impact testing system. In a healthy male, Howarth and Rome (1996) reported that a sock composed of 87% wool also demonstrated significant increases in shock attenuation while walking on a treadmill utilising a shock-meter (piezoelectric accelerometer connected to a meter unit). Furthermore, Blackmore et al. (2011) investigated a sock composed of 56% wool using participants walking over a force platform and reported significant increases of 0.0016 s in time to peak impact force.

When compared to a control condition the smallest decrease in peak impact force (3%) and loading rate (4%) was observed in sock seven, with the smallest increase in the time to peak impact force (8%) observed in sock eight. These socks were composed primarily of nylon (sock seven: inner sock 100%, outer sock 14%; sock eight: 96% nylon) and cotton (sock seven: inner sock 40%). Nylon has previously been described as having a high degree of elasticity and viscoelasticity but lacks tensile strength (Howarth and Rome, 1996) whereas cotton socks have been ineffective at attenuating shock (Howarth and Rome, 1996) and plantar pressures (Blackwell et al., 2002; Flot et al., 1995). However, it has been suggested that nylon would have a shock attenuating effect if incorporated into the plantar aspect of a sock (Howarth and Rome, 1996), which was demonstrated in the present study, although the magnitude of this effect which is the smallest in the current study may have been reduced by the limited thickness of the socks.

When tested in conjunction with a shoe and compared to a shoe only control condition, athletic socks continued to significantly decrease peak impact force and loading rate by up to 14% and 35%, respectively, and significantly increase the time to peak impact force by up to 32%. The largest decrease in peak impact force and loading rate was observed in sock two, whereas the largest increase in time to peak impact force was observed in sock three, which were composed predominantly of Thermocool® (inner sock 80%, outer sock 50%) and Coolmax® (50%) polyester respectively. In addition, similar to the sock only conditions, the smallest decrease in peak impact force (2%) and loading rate (6%) was observed in sock seven, whereas the smallest increase in time to peak impact force (5%) was observed in sock eight.

Table 4
The relationship (correlation coefficient, r) between sock thickness and the three dependant variables in the sock and sock/shoe conditions.

Condition	Peak impact force		Time to peak impact force	Loading rate
Sock only	r	−0.615	0.728	−0.718
	P	0.025	0.005	0.006
Sock/shoe	r	−0.388	0.464	−0.486
	P	0.190	0.111	0.093

Although the socks performed well when tested in conjunction with the shoe, they did not perform as well as the sock only conditions. Previous research into athletic footwear and insoles (Chiu, 2005) has suggested that insoles could absorb a greater ratio of impact energy under low impact conditions. During high impact conditions, it has been reported that the absorption qualities of the insoles were masked by the greater absorption qualities of the shoe (Chiu, 2005). Based on these previous findings, it is suggested that the disparity observed in the current study between the attenuating properties of the socks alone and when tested in conjunction with the shoe may be due to the superior attenuating properties of the shoe masking the attenuating properties of the socks. If this is so, then athletic socks may respond differently when tested with shoes of differing cushioning properties and therefore warrants further investigation.

In an attempt to limit confounding variables and decrease the variability associated with the results, an impact testing methodology was used. Although this is not representative of a sock's designated use, it allows the quantification of the attenuation properties of the sock alone as well as the sock/shoe unit without any other variables that are associated with participant testing affecting the results (e.g. changes in joint kinematics, leg stiffness and translation of centre of mass). It has been suggested that mechanical testing alone cannot predict how materials will respond in a participant-based population (Stiles and Dixon, 2007), although as a method of assessment or classification it can provide useful information (Young and Fleming, 2007). Therefore, now that the cushioning properties of the athletic socks have been established, future research should consider the shock attenuating properties of the sock and the sock/shoe unit in participant-based studies with athletes.

5. Conclusion

This is the first study to determine the cushioning properties of athletic socks using an impact testing method that mimics loading conditions similar to those experienced during running in a laboratory environment. The current study found that athletic socks attenuate peak impact force by up to 20%, delay the onset of loading by up to 33% and reduce the loading rate by up to 47% under impact testing conditions. A strong relationship was also observed between sock thickness and reductions in impact force when testing the socks alone. Furthermore, when tested in conjunction with a shoe, athletic socks attenuated peak impact force by up to 14%, delayed the onset of loading by up to 32% and reduced loading rate by up to 35% although these effects were less than that in the sock alone condition. This is attributed to the superior attenuating properties of the shoe masking the attenuating properties of the socks. This study identifies that athletic socks are capable of reducing impact forces and loading rates in the absence of a participant population. It also provides baseline information regarding the cushioning properties of socks which can be used in future work with participants. Therefore, it is concluded that athletic socks demonstrate cushioning properties under impact testing conditions.

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