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The influence of boot design on exercise associated surface temperature of tendons in horses

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RESEARCH PAPER

Abstract

Sport horses frequently injure tendons of the lower limb. Tendon boots are commonly applied for structural support and trauma prevention during competitions. However these boots may increase heat stress in the area. Two separate studies were carried out with the aim to improve understanding of the effect of boots on heat around the tendon area. Study 1 measured heat emitted from two types of boots (traditional and perforated, cross-over design) covering the superficial digital flexor tendon in 4 horses during a set ridden and lunged exercise test. Study 2, a field test, measured the effect of boot style (traditional, perforated and open fronted) on skin surface temperature in 130 horses, after completing a cross country event test (either a BE 100 three day event or a CIC* – two day short format event). An infrared thermometer was used to measure temperatures during both studies. Boots designed with perforations demonstrated greater heat emissions than traditional (non-perforated) boots (+3.5 ° C, $P<0.01$). In Study 2 mean tendon surface temperature for perforated type boots (28.0 °C) was significantly lower than for traditional boots (32.3 °C) and for open fronted tendon boots (31.1 °C) ($P<0.001$). As this was an applied field study, additional environmental factors, such as speed and fitness level of horses, may have influenced results. Although exact mechanisms leading to these findings and the link between heat and tendon injury needs to be researched further, it is advisable to design boots to minimise tendon exposure to high temperatures, which may contribute to tendon injury.

Keywords: heat, equine, protective equipment, thermal imaging

1. Introduction

Injuries of the superficial digital flexor tendon (SDFT) are one of the most common causes of lameness in the Thoroughbred race horse (Patterson-Kane and Firth, 2009) and in athletic sports horses (Murray *et al.*, 2006). In National Hunt racing (over jumps) 89% of all ligament and tendon injuries are to the SDFT (Ely *et al.* 2009). Singer *et al.* (2008) found 24% of all injuries (0.45% of starts recorded at events) during the cross country phase in eventing are related to tendons and ligaments. In addition, 43% of injuries sustained during training for eventing are tendon or ligament injuries and 36% of these involved the SDFT (Singer *et al.*, 2008). The human Achilles tendon (AT) is considered functionally equivalent to the equine SDFT and in humans the AT has a pivotal role in saving energy during high-speed locomotion, by reducing muscular work, which leads to increased heat in the area (Malvankar and Khan, 2011).

Wilson and Goodship (1994) measured heat produced inside tendons *in vivo* and found temperatures of 45 °C in the SDFT and concluded that this heat could be a major contributor to degenerative changes in tendons of equine and human athletes. At temperatures of 45-48 °C over a period of 10 min a rapid decline of tendon fibroblast activity takes place, resulting in cell death (Birch *et al.*, 1997; Burrows *et al.*, 2008). Yamasaki *et al.* (2001) also showed *in vitro* that when tendons were exposed to 45 °C for 10 min only 27% of tenocytes survived and showed *in vivo* that temperatures of 45 °C were reached after a short gallop on the track. Although tenocytes have a higher heat resistance than other cells these temperatures at shorter time periods are likely to influence tendon matrix quality leading to some damage of tenocytes (Patterson-Kane and Firth, 2009; Smith, 2004). The extrapolation of the *in vitro* and *in vivo* data on core temperatures to *in vivo* tendon injuries should be made with caution, as this has not yet been directly linked.

In order to prevent mechanical injury to the lower limb from over reach, hitting jumps or during a fall, various types of boots are worn routinely during jumping competitions (Murphy, 2008). The encasement of the lower limb by the boot may increase heat stress to soft tissue but to date *in vivo* research in this area is scarce. The design and structure of horse boots varies according to their purpose. Traditional boots, such as brushing boots enclosing the limb distal to the carpus and proximal to the metacarpophalangeal joint used to be made of leather with leather straps. Open-fronted tendon boots were generally worn by show jumpers, providing extra padding around the tendons but being open dorsally to 'remind horses to pick up their feet' over jumps (Murphy, 2008). Modern boots are often made of a mix of more pliable and softer cushioning materials which are cheaper, easier to clean and maintain. Polyvinyl chloride (PVC) is a water-proof rigid thermoplastic polymer with added plasticizers for flexibility. It has a thermal conductivity of 0.14-0.17 W/m-K (the lower the number, the more insulation it provides). Polycarbonate, another thermoplastic polymer, with a thermal conductivity of 0.19-0.22 W/m-K is used because of its light weight, impact strength (Izod 600-850 J/m) and temperature resistance (Rouabah *et al.,* 2007). Most modern horse boots combine a softer inner layer such as neoprene (polychloroprene, thermal conductivity of 0.054 W/m-K – high insulation) and a synthetic rubber which also provides insulation (e.g. used in wetsuits), and aids prevention of rubbing (Bardy *et al.,* 2006). Thermoplastic elastomers (generally a mixture of plastic and rubber) are used for their softness and durability (Holden *et al.,* 2000) imparting high elastic properties and these have a thermal conductivity of 0.209-0.251 W/m-K. Combining these materials in a boot will prevent endogenous heat dispersal. Heat dissipation from the surface of the limb without a boot occurs through evaporation and radiation. With a boot further conduction is required through the boot material followed by radiation from the boot surface.

In recent years a focus on prevention of injury and a deeper understanding of tendon injuries has led to the development of boots with perforation holes (often called 'air-cooled' boots), which are marketed as 'allowing better dissipation of heat through air circulation to the limb'. However, no research, to the knowledge of these authors, has been published which tests this theory. The overall aim of the studies presented here was to measure the effect of fully closed versus perforated boots on SDFT skin surface temperature in exercising horses. The aim of Study 1 was to measure heat emitted from either traditional closed boots or novel air-perforated boots after controlled exercise tests, while Study 2 measured the effect of boot style on tendon skin surface temperature following a field test.

2. Materials and methods

Experimental design

The study passed the procedures of the Ethical Review Committee at Nottingham Trent University. Study 1 employed a controlled cross-over design with 4 horses. The treatment consisted of traditional designed tendon boots or a perforated (air-flow) boot. Study 2 was a field study and measured SDFT skin surface temperature of 130 horses immediately after completing high intensity exercise (cross country event).

Thermometer

The Raytek Raynger ST20 Laser Thermometer (Berlin, Germany) (non-contact infrared thermometer with a temperature range of -32 to 535 °C) was used to measure temperatures. The Raytek Raynger ST20 is usable in all weather conditions and was used in both studies for speed and ease of measurement. Temperatures were taken approximately 5 cm from the limb according to manufacturer's guidelines.

Study 1: heat emission from horse boots after controlled exercise tests

Four sound German Warmbloods (550±50 kg bodyweight, 6-13 years old) were selected. The study consisted of two parts, a lunging test and a ridden exercise test which occurred over four days with two different phases (cross-over design). The Eskadron (Werther, Germany) more 'traditional' cross country boot and the New Equine Wear 'perforated' boots (Chippenham, UK) were tested on all four limbs. Both boots were chosen as they were made similarly with a PVC upper surface and Neoprene cushioning material underneath. Each test was performed twice and horses wore one set of boots (e.g. traditional) on left limbs while wearing the other set (e.g. perforated) on the opposite leg in a further cross-over design. Therefore, each leg was used as a separate unit with the opposite leg as control treatment so that measures were taken simultaneously reducing any environmental effects over time. Measurements were always performed in the same order to eliminate timing results (i.e. temperature was taken from left fore and hind legs first, then from right fore and hind resulting in a further cross-over between boot types).

The set exercise tests (same rider or handler) were carried out in an arena with a sand surface and included 10 min warm up in walk followed by 5 min of trot in each direction, and a canter for: (1) ridden test: 2.5 minutes on each rein; and (2) lunging test: 1 min on each rein.

After the exercise, temperatures were taken in three areas to assess heat emissions with the boot still in place at the lateral aspect of the boot (area of SDFT): just 1 cm above the top edge of the boot (top), the mid-point (middle – midway between the carpus and the metacarpal-phalangeal joint while boot was still on) and 1 cm below the bottom edge of the boot (bottom) on all four legs.

Study 2: tendon skin surface temperature following a field test

The field test was carried out at the International Horse Trials at Aldon. 130 horses from two classes were used: a British Eventing (BE 100) three day event (length: 3,000 m; height/no. of jumps: 1.0 m/25, n=61); and a Fédération Equestrienne International (FEI) Concours Internationale Combined One Star (CIC)* two day short format event (length: 3,000 m; height/no. of jumps: 1.1 m/24, n=69). Horses in the three day BE 100 event also have completed the field and track phases (incl. 4,000 m endurance) on the same day prior to the cross country event. 21 types of boots could be distinguished according to style and manufacturer. Results for boots were pooled into three groups according to style: a traditional boot design closed all around the leg (traditional, n=92); boots with a design using holes, perforations or mesh design to allow for air to cool the leg (perforated, n=24), open fronted tendon boots (tendon boots, n=12); and no boots (n=2).

Temperature of the left front leg only was taken, mid-way between the carpus and the metacarpo-phalangeal joint on the SDFT, immediately after horses had crossed the finish line after the boot had been removed (one leg only was used purely because of speed and the horses needing to be cooled down). A few horse owners insisted on removal of boots immediately after the finish line of the Field test and therefore temperature had to be measured in all horses after removal of the boot.

Statistical analysis

Statistical analyses was carried out using SPSS version 17.00 (IBM, Armonk, NY, USA). The significance level was set as $P<0.05$. Data were analysed for normal distribution (Kolmogorov-Smirnov) and analysis of variance (ANOVA) was applied, testing for differences between boots and for effects and interactions between left and right, fore and hind, exercise and phases (Study 1). For Study 2, ANOVA was used to test for effect of boots and cross country class. Unless stated otherwise, means are reported with standard errors.

3. Results

Heat emission from traditional closed and air-perforated horse boots

Study 1 showed no differences between left and right legs, fore and hind legs, or according to phases and no interaction was identified. Therefore, independent leg data were pooled and when all temperature areas (top, middle and bottom) were considered together there was no significant difference in heat emissions between the two boots, but there was a significant difference between areas irrelevant of boots ($P<0.001$; n=8; Figure 1).

There was a significant difference in heat emissions from the middle area of boots between exercises and between boots ($P<0.01$) (Table 1).

Effect of boot style on tendon skin surface temperature during field tests

Study 2 showed that there was no significant difference in limb temperatures between the two eventing classes although the perforated boots showed a much narrower distribution of measures for the CIC* Event (Figure 2).

There was a significantly lower temperature under perforated boots compared to open-fronted tendon boots ($P<0.001$) and compared to traditional boots ($P<0.001$, Table 2). The difference between open-fronted and traditional boots was slight, but significant ($P<0.05$) and much lower temperatures were recorded for the two horses, who did not wear boots.

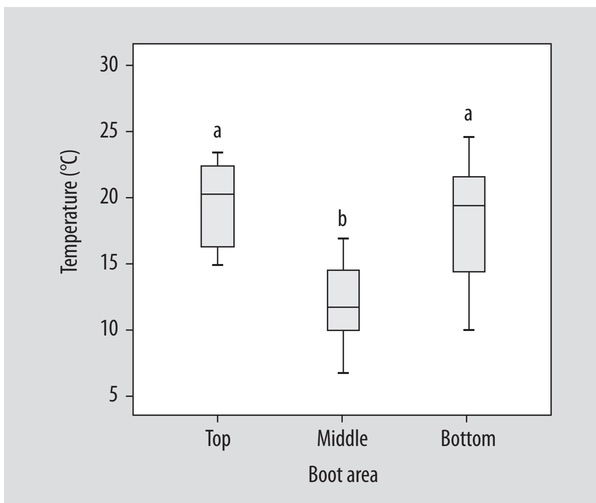

Figure 1. Distribution of mean heat emissions of outer surface of boots for horses undergoing two exercise tests depending on measurement area (a,b – significantly different; *P*=0.000, F=18; ANOVA, n=8).

Table 1. Mean heat emissions from the outer surface in the middle of the boot according to boots and exercise for 4 horses.

	n	Treatment	Temperature (°C) ± standard deviation	*P*-value[1]
Traditional	4	lunging	11.63±1.9	*P*=0.064, F=5.1
		ridden	8.54±1.9	
Perforated	4	lunging	15.46±2.0	*P*=0.074, F=4.7
		ridden	12.00±2.9	
Boots[2]	8	traditional	10.08±2.4	*P*=0.005, F=11
		perforated	13.73±3.0	
Exercise[3]	8	lunging	13.54±2.7	*P*=0.009, F=9.6
		ridden	10.27±3.0	

[1] Univariate Anova.
[2] ×2 Exercises.
[3] × Boots.

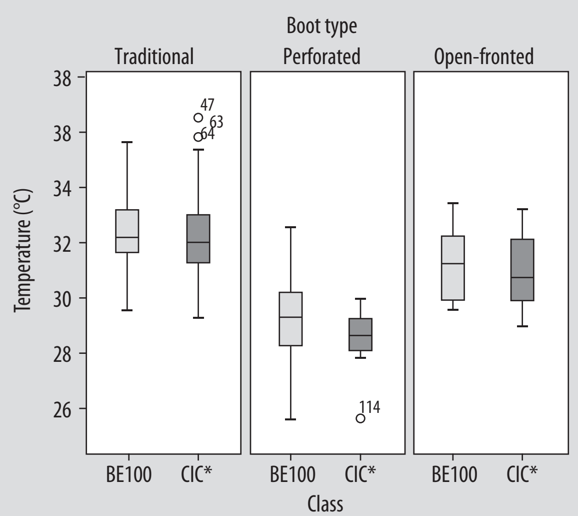

Figure 2. Distribution of temperatures under the tendon boots at the finish line of two Cross Country Events (BE 100 – 3 day event with roads and tracks, n=61; CIC* = 2 day show jumping and cross country short format event, n=69).

Table 2. Mean, minimum and maximum temperatures (°C) of skin surface according to type of boot for horses upon completion of the cross country phase of a one day event.

Boot type	n	Mean ± SE[1]	Min	Max
Traditional	92	32.33±0.17[a]	29.3	36.5
Perforated	12	28.66±0.32[b]	25.6	32.6
Open-fronted	24	31.10±0.47[c]	28.9	33.4
No boot[2]	2	21.70	21.2	22.2

[1] Anova, Bonferroni: SE = standard error; [ab, bc] *P*<0.001; [ac] *P*<0.05.
[2] Not included in statistical analysis.

4. Discussion

The aims of this study were to measure the effect of boot style on heat emissions from the surface of boots following light exercise and on skin surface temperature under the boots following heavy exercise. The infrared thermometer was ideal for temperature measurements in the competition environment, as it could be used quickly and easily. The slightly unconventional application of different boots on opposing legs was used in Study 1 to help eliminate environmental influences.

As the thermal image showed a large change in temperatures between the centre of the boots and the top and bottom, it was decided to take mean measurements from these three points for both measurement devices. In Study 1 there were significantly lower heat emissions from the middle of both boots (*P*<0.01) compared to the top and bottom showing a stronger insulation effect of boots in this area which may be due to a greater insulating effect or it could be due to less heat in the leg underneath those areas relative to the more proximal and distal areas. Although this area of the of the SDFT has been found at higher risk of developing lesions, Birch *et al.* (2002) did not find a change in strength or composition of tendons in this area. These authors actually pointed towards the possibility of hypoxia and/or hyperthermia in this area causing site-specific tendon lesions in the SDFT (Birch *et al.*, 2002). Further research on the SDFT in various areas with and without a boot needs to be carried out to establish a possible link.

The boots chosen in Study 1 were made of the same material and thickness, with the main difference being the perforations for the air cooled boot. Results for the perforated boots may indicate that greater heat emission and thus heat dissipation took place by a mean of +3.5 °C (±1.1 standard error) from traditional boots. This interpretation is further supported by a reduced temperature (-3.7 °C ±0.13 standard error) measured in the same metacarpal area on removal of the perforated boots compared to the traditional boots in Study 2. These two studies have to be treated separately due to differences in exercise level and design as well as the different range of boots used by competitors in Study 2. In favour of some comparison is the high number of participants of the field study and that the results seem to show some convergence. It is unfortunate that, due to circumstances beyond our control, it was not possible to take similar measurements in both studies.

The difference in the temperature lost from the middle of the boots during lunging was higher than when horses were ridden (+3.1 °C ±1.3 standard error), although exercise duration was 3 min shorter when horses were lunged. The balanced design of Study 1, with repetition in each horse, as well as no phase effects point towards this being a true effect. Differences may be due to changes in biomechanical use of the limb due to working on a tighter circle or due to speed and collection via rider/handler influence.

To date there is a lack of data available in measuring differences in leg temperatures between horses according to their heart rates and speed and other factors in competitions. Study 2 can be summed up as a pilot field study to record what types of boots are used and to measure *in vivo* temperatures after 130 horses completed a cross country event. The range of temperatures measured was between 29-37 °C (traditional boots) and 26-33 °C (perforated boots). Differences within and between groups could be due to boot design, speed and fitness level. To eliminate or measure these factors would be desirable in future research. The insulation effect of boots overall was shown by the limb temperatures of the two horses competing without boots (21-23 °C) which were considerably lower than those wearing any type of boots (mean 30.7 °C). In an ideal situation a higher sample population with no boots could confirm these results. The open-fronted tendon boots did not result in a relevant reduction in temperature (-1.2 °C) compared to traditional fully enclosed boots.

Although long term training and mechanical stress during exercise over time may play a primary role in injury (Ely *et al.,* 2009), additional heat stress may contribute to final aetiology (Birch *et al.*, 2002; Wilson and Goodship, 1994). Birch *et al.* (1997) reported that a tendon temperature of 39 °C already leads to a 4% decrease of tendon fibroblast viability. Wilson and Goodship (1994) reported that the skin temperature was around 5.4 °C cooler than the tendon core temperature in their *in vivo* study at an ambient temperature of 2 °C, when horses galloped for 2 min on a treadmill. The maximum skin surface temperature in Study 2 was 36.5 °C for traditional boots, however, the ambient temperature during the horse trial was much warmer at 9 °C (Met Office; Weather station, Yeovilton, UK). In addition the thermometer was only commercially calibrated and had not been re-calibrated against absolute temperature measurements prior to commencement of the trial. This limits direct temperature comparison between studies. However, following these results, the possible link between heat stress and boot design warrants further exploration.

Future research could focus on measuring temperatures during the actual exercise with a motion thermal imaging camera or electrode surface temperature time-lapse recording equipment while looking at speed and heart rate of horses, together with final performance. This would allow for evaluation of temperature development from onset of exercise and could also look at the effect of cooling down periods and the influence of water fences on the limb temperature. Furthermore, temperatures developed under the boots or bandages of national hunt and racehorses should be evaluated. In addition effect of boot material on heat insulation needs to be investigated further.

5. Conclusion

During both studies differences in heat retention according to the type of boot were recorded. This points towards a possible cooling effect of air perforated boots but further more detailed research is required to test other influencing factors and to test the protective properties of these boots. Although exact mechanisms leading to these findings and the link between heat and tendon injury needs to be proven *in vivo*, based on current knowledge, it is advisable to design boots to minimise tendon exposure to high temperatures.

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Conflict of interest

None of the authors of this paper has a financial relationship with any organisation that could inappropriately influence or bias the content of this paper.

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