How does exercise intensity and type affect equine distal tarsal subchondral bone thickness?

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Murray RC, Branch MV, Dyson SJ, Parkin TD, Goodship AE. How does exercise intensity and type affect equine distal tarsal subchondral bone thickness? J Appl Physiol 102: 2194–2200, 2007. First published March 1, 2007; doi:10.1152/japplphysiol.00709.2006.—Adaptation of osteochondral tissues is based on the strains experienced during exercise at each location within the joint. Different exercise intensities and types may induce particular site-specific strains, influencing osteochondral adaptation and potentially predisposing to injury. Our hypotheses were that patterns of equine distal tarsal subchondral bone (SCB) thickness relate to the type and intensity of exercise, and that high-intensity exercise leads to site-specific increases in thickness. SCB thickness was measured at defined dorsal and plantar locations on magnetic resonance images of cadaver tarsi collected from horses with a history of low [general purpose (n = 20) and horse walker (n = 6)] or high [elite competition (n = 12), race training (n = 15), and treadmill training (n = 4)] exercise intensity. SCB thickness was compared between sites within each exercise group and between exercise groups. SCB thickness in elite competition and race training, but not treadmill training, was greater than low-intensity exercise. For general purpose horses, lateral SCB thickness was greater than medial throughout. Horse walker exercise led to relatively thicker lateral and medial SCB compared with the midline. Elite competition was associated with increased SCB thickness of the proximal small tarsal bones medially and the distal bones laterally. For race training and treadmill training, there were minimal differences between sites overall, although the lateral aspect was greater than medial, and medial greater than midline at a few sites for race training. In conclusion, different types of high-intensity exercise were associated with different patterns of SCB thickness across the joints from medial to lateral and proximal to distal, indicating that both exercise intensity and type of exercise affect the SCB response at any particular site within the equine distal tarsal joints.

Magnetic resonance imaging; osteochondral adaptation

Osteochondral structure is related to the loading history of the joint and position within the joint (11, 22, 23, 36, 37). Adaptation of the osteochondral tissues is based on the strains experienced during exercise at each location within the joint. Therefore a joint is likely to vary in structure, depending on the type and intensity of exercise that is undertaken by the individual. However, repetitive overloading is associated with osteochondral failure (23), so it is important to understand the balance between joint adaptation, which may prevent pathology, and the development of pathology during training.

It has been demonstrated that mechanical loading is not only a primary stimulus for adaptation but is also implicated in joint degeneration (23, 27, 30, 33, 34). Therefore the type and intensity of exercise and associated tissue adaptation are important factors in understanding the presumed association of exercise with joint degeneration. Like humans, horses develop naturally occurring osteoarthritis, and exercise-associated joint degeneration, and can provide an insight into the mechanisms of response to loading and joint degeneration (13, 23, 28, 29).

Differences have been seen in bone mass and bone turnover between human power athletes (sprinters, jumpers, hurdlers, multievent athletes), endurance athletes (middle distance runners, distance runners), and nonathlete controls, suggesting that different strain types and magnitude cause bone to remodel at different rates (1). Equine athletes also train for different sport types and intensities, but there has been little investigation of the effect of training for different sports and levels on joints predisposed to osteochondral damage. Racehorses are trained at fast speeds to race at a gallop, with compression strains at the dorsal aspect of the third metacarpal bone reported to be in excess of ~4,000 microstrains (8). Dressage horses spend most time working on lower impact surfaces and undertake gymnastic-type exercises, including specific turns, circles, and sideways movements at a variety of speeds. Event horses undertake both dressage-type exercise and jumping at lower speeds than racehorses. Horses walking, trotting, and cantering experience lower compressive strains than at gallop. It was reported that peak compressive strains in the third metacarpal bone varied from approximately ~400 at walk to ~1,600 at trot, and ~2,800 microstrains at canter (8). For walking in circles, peak strains in the metacarpus varied between medial, dorsal, and lateral aspects (7). Bone strain is therefore considered to be lower than in the galloping racehorse, but direction of strain is more variable.

Treadmill and mechanical horse-walker exercise are used for both physiological investigation and for training of equine athletes. However, there has been little comparison of subchondral bone (SCB) structure between treadmill and over-ground training or the effect of exercising in a circle on a mechanical horse walker. In the equine carpus, high-intensity galloping treadmill exercise was associated with increased SCB thickness and evidence of cartilage degeneration at sites subjected to high loads (23) compared with horses undergoing horse-walker exercise. However, in equine metacarpophalangeal joints, treadmill exercise was associated with increased SCB volume, whereas horses trained over ground demonstrated evidence of SCB microfracture and failure (30). Further investigation of the effects of treadmill and horse-walker exercise on equine
joints could be helpful for design of future studies or training programs.

The distal aspect of the equine tarsus is a frequent clinical site of osteochondral degeneration. The distal aspect of the tarsus is loaded primarily in compression, with maximal strain dorsally and laterally (35). The maximum compression strain recorded was $-600 \times 10^{-6}$ m/m (35). In a previous study, radiopharmaceutical uptake patterns in the equine tarsus supported increased osteoblastic activity dorsally and laterally compared with other sites (26). SCB thickness was greatest dorsally and laterally in tarsi from horses without pain with a history of low-intensity, general purpose (GP) exercise (3), also supporting this loading pattern. However, tarsal SCB structure has not previously been investigated in horses undergoing different exercise types or intensities.

It is not known whether different patterns of loading during different gaits, or magnitude of the same load pattern have a greater effect on SCB structure. To understand how exercise history may influence tarsal SCB structure and to determine whether this may predispose to osteochondral pathology, it is important to have an appreciation of the structure of SCB in horses undergoing different types of sport.

This investigation tested the hypotheses that high-intensity exercise is associated with greater SCB thickness at dorsal sites in the equine distal tarsus than low-intensity exercise and that patterns of SCB thickness in the equine tarsus relate to the type and intensity of exercise.

The objectives were 1) to measure dorsal and plantar SCB thickness using magnetic resonance images, on the proximal and distal aspects of the central (CT) and third tarsal (T3) bones and the proximal aspect of the third metatarsal (MT3) bone at defined standard sites in tarsi from horses with a history of different exercise types and no hindlimb lameness; and 2) to compare patterns of SCB thickness between exercise groups.

**MATERIALS AND METHODS**

**Sample Collection**

Twenty cadaver tarsi were collected from 11 mature horses (mean age 8.75 yr, range 5–15 yr) with a history of low-intensity GP exercise, defined as hacking and unaffiliated competition. The breed distribution was four Thoroughbred, nine Thoroughbred-cross, and seven Warmblood. Twelve cadaver tarsi were collected from eight mature horses (mean age 11.25 yr, range 9–13 yr) with a history of elite competition, defined as dressage at advanced medium level or above ($n = 4$) or eventing at advanced level or above ($n = 8$). Breeds of horses were eight Thoroughbred and four Warmblood. All horses were in work at the time of euthanasia except two, which had been rested for 2 and 6 wk, respectively. Fifteen cadaver tarsi were collected from 13 Thoroughbred horses (mean age 6.53 yr, range 3–12 yr), with a history of high-intensity race training, collected as part of an investigation into fatal distal limb fractures in racing Thoroughbreds in the United Kingdom (32). All racehorses had been trained for a minimum of 33 days (mean 122 days) with a mean of 14 (range 10–24) furlongs/wk fast work. Six cadaver tarsi were collected from six previously untrained 2-yr-old Thoroughbred mares that had undergone low-intensity exercise on a mechanical horse walker, restricted to 40 min walking in both directions daily for 19 wk. Four cadaver tarsi were collected from four previously untrained 2-yr-old Thoroughbred horses that underwent high-intensity treadmill exercise designed to simulate race training, for 19 wk on a high-speed treadmill at a 3% incline (27). There were therefore two low-intensity exercise groups (GP and horse walker) and three high-intensity exercise groups (elite competition, race training, treadmill exercise).

Tarsi were only included if horses had no history or clinical evidence of hindlimb lameness, and there was no radiographic abnormality of the tarsal joints. All cadaver tarsi were obtained from veterinary clinics and were collected from horses undergoing humane destruction for reasons other than this study. Tarsi were collected within 6 h of death for all groups except race training, which were collected within 36 h of death. Limbs were stored frozen at $-20^\circ$C. For magnetic resonance imaging, tarsi were thawed at room temperature for 24 h. In a previous study, freezing and defrosting equine specimens did not alter image quality (39).

**Magnetic Resonance Imaging**

Each tarsus was positioned as if in right lateral recumbency in an intact horse in a human extremity radiofrequency coil (Medical Advances, Milwaukee, WI) with the distal tarsal joints centered in the isocenter of the magnet. Three-dimensional spoiled gradient echo...
Table 1. SCB thickness at medial locations in equine tarsal bones from horses with a history of low-intensity GP exercise, low-intensity horse-walker exercise, high-intensity elite competition, high-intensity race training, and high-intensity treadmill exercise.

<table>
<thead>
<tr>
<th>Location</th>
<th>Low-Intensity GP</th>
<th>Horse Walker</th>
<th>Elite Competition</th>
<th>Race Training</th>
<th>Treadmill Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal CT</td>
<td>3.82±0.69</td>
<td>3.63±0.58</td>
<td>4.87±0.94</td>
<td>4.44±0.75</td>
<td>3.53±0.47</td>
</tr>
<tr>
<td>Distal CT</td>
<td>2.68±0.74</td>
<td>2.96±0.91</td>
<td>3.97±0.74</td>
<td>3.20±1.09</td>
<td>2.10±0.63</td>
</tr>
<tr>
<td>Proximal T3</td>
<td>2.29±0.89</td>
<td>2.64±0.72</td>
<td>2.99±0.63</td>
<td>3.66±2.48</td>
<td>2.45±0.49</td>
</tr>
<tr>
<td>Distal T3</td>
<td>2.87±3.15</td>
<td>2.36±0.54</td>
<td>2.97±0.73</td>
<td>3.25±1.65</td>
<td>2.44±0.21</td>
</tr>
<tr>
<td>Proximal MT3</td>
<td>3.23±0.61</td>
<td>3.59±0.99</td>
<td>4.57±0.75</td>
<td>4.23±0.92</td>
<td>2.94±0.40</td>
</tr>
</tbody>
</table>

Values are means ± SD in mm of subchondral bone (SCB) thickness at midline position (positioned 50% of the width of the tarsus from the medial aspect) in equine tarsal bone. GP, general purpose; CT, central tarsal bone; T3, 3rd tarsal bone; MT3, 3rd metatarsal bone. Measurements were obtained using magnetic resonance imaging. a,b,c,d,e Exercise groups that share superscript letter are significantly different at each location (P < 0.05).

Table 2. SCB thickness at midline locations in equine tarsal bones from horses with a history of low-intensity GP exercise, low-intensity horse-walker exercise, high-intensity elite competition, high-intensity race training, and high-intensity treadmill exercise.

<table>
<thead>
<tr>
<th>Location</th>
<th>Low-Intensity GP</th>
<th>Horse Walker</th>
<th>Elite Competition</th>
<th>Race Training</th>
<th>Treadmill Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal CT</td>
<td>2.45±0.96</td>
<td>2.59±1.09</td>
<td>3.81±0.90</td>
<td>4.13±1.23</td>
<td>2.73±0.83</td>
</tr>
<tr>
<td>Distal CT</td>
<td>2.13±0.96</td>
<td>1.96±0.54</td>
<td>2.58±1.41</td>
<td>2.72±1.02</td>
<td>2.46±1.27</td>
</tr>
<tr>
<td>Proximal T3</td>
<td>2.10±0.73</td>
<td>1.92±0.68</td>
<td>2.52±1.25</td>
<td>3.39±3.07</td>
<td>2.11±0.36</td>
</tr>
<tr>
<td>Distal T3</td>
<td>1.95±0.78</td>
<td>2.11±0.40</td>
<td>2.96±1.19</td>
<td>3.96±2.99</td>
<td>2.19±0.51</td>
</tr>
<tr>
<td>Proximal MT3</td>
<td>3.23±1.36</td>
<td>3.18±1.00</td>
<td>4.88±2.18</td>
<td>9.63±7.96</td>
<td>2.42±0.29</td>
</tr>
</tbody>
</table>

Values are means ± SD in mm of SCB thickness at midline locations (positioned 50% of the width of the tarsus from the medial aspect) in equine tarsal bones. Measurements were obtained using magnetic resonance imaging. a,b,c,d,e Exercise groups that share superscript letter are significantly different at each location (P < 0.05).
Table 3. SCB thickness at lateral locations in equine tarsal bones from horses with a history of low-intensity GP exercise, low-intensity horse-walker exercise, high-intensity elite competition, high-intensity race training, and high-intensity treadmill exercise

<table>
<thead>
<tr>
<th>Location</th>
<th>Low-Intensity GP</th>
<th>Horse Walker</th>
<th>Elite Competition</th>
<th>Race Training</th>
<th>Treadmill Exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proximal CT</td>
<td>3.54±1.16</td>
<td>3.77±0.68</td>
<td>4.20±0.96</td>
<td>5.21±2.46</td>
<td>3.43±1.28</td>
</tr>
<tr>
<td>Distal CT</td>
<td>3.62±0.80</td>
<td>3.54±1.10</td>
<td>3.35±0.60</td>
<td>4.56±2.48</td>
<td>3.63±0.68</td>
</tr>
<tr>
<td>Proximal T3</td>
<td>2.35±1.15</td>
<td>2.20±1.36</td>
<td>1.85±1.11</td>
<td>2.84±1.17</td>
<td>2.13±0.76</td>
</tr>
<tr>
<td>Distal T3</td>
<td>3.81±1.21</td>
<td>4.06±0.64</td>
<td>4.65±1.66</td>
<td>5.91±1.76</td>
<td>3.28±0.57</td>
</tr>
<tr>
<td>Proximal MT3</td>
<td>4.77±2.92</td>
<td>3.76±0.81</td>
<td>9.12±2.15</td>
<td>14.09±7.43</td>
<td>3.19±0.57</td>
</tr>
</tbody>
</table>

Values are means ± SD in mm of SCB thickness at lateral locations (positioned 70% of the width of the tarsus from the medial aspect) in equine tarsal bones. Measurements were obtained using magnetic resonance images. *Exercise groups that share superscript letter are significantly different at each location, P < 0.05.

Age and Horse Effect (Generalized Linear Mixed Model)

The differences in SCB thickness between the elite competition and/or race training groups and the low-intensity GP group were not significantly altered when the effect of age and horse level clustering were taken into account. The same regions of SCB were identified as being significantly greater thickness in the elite competition and/or race training groups.

Patterns of Variation in SCB Thickness Within Each Exercise Group

Medial to lateral comparison of dorsal SCB thickness (Tables 1–3; Figs. 2 and 3). LOW-INTENSITY EXERCISE: GP EXERCISE. For low-intensity GP exercise, lateral SCB thickness was significantly greater than medial on the distal aspects of the CT and T3 bones (Fig. 3) and the proximal aspect of the MT3 bone (P ≤ 0.017) and significantly greater than midline on the proximal and distal aspects of the CT bone, distal aspect of the T3 bone, and proximal aspect of the MT3 bone (P ≤ 0.009). Medial SCB thickness was significantly greater than midline on the proximal and distal aspects of the CT bone (P ≤ 0.032).

LOW-INTENSITY EXERCISE: HORSE-WALKER EXERCISE. For low-intensity horse-walker exercise, lateral SCB thickness was significantly greater than medial on the distal aspect of the T3 bone (P < 0.001) and significantly greater than midline on the
proximal and distal aspects of the CT bone, the distal aspect of the T3 bone, and the proximal aspect of the MT3 bone ($P \leq 0.029$). Medial SCB thickness was significantly greater than midline on the proximal and distal aspects of the CT bone and the proximal aspect of the MT3 bone ($P \leq 0.040$).

**HIGH-INTENSITY EXERCISE: ELITE COMPETITION.** For elite competition, lateral SCB thickness was significantly greater than medial and midline on the distal aspect of the T3 bone and the proximal aspect of the MT3 bone ($P \leq 0.009$). Medial SCB thickness was significantly greater than lateral on the proximal aspects of the CT and T3 bones ($P \leq 0.017$) and significantly greater than midline on the proximal and distal aspects of the CT bone ($P \leq 0.011$).

**HIGH-INTENSITY EXERCISE: RACE TRAINING.** For high-intensity race training, lateral SCB thickness was significantly greater than medial and midline on the distal aspects of the CT and T3 bones ($P \leq 0.010$). Medial SCB thickness was significantly greater than midline on the distal aspect of the CT bone ($P = 0.034$).

**HIGH-INTENSITY EXERCISE: TREADMILL EXERCISE.** For high-intensity treadmill exercise, lateral SCB thickness was significantly greater than medial on the distal aspect of the CT bone ($P = 0.002$).

**Dorsal to plantar comparison (Fig. 4).** For low-intensity GP exercise, dorsal SCB thickness was significantly greater than the plantar aspect on the proximal and distal aspects of the CT bone ($P \leq 0.003$). In elite competition, dorsal SCB thickness was significantly greater than the plantar aspect on the proximal and distal aspects of the CT bone, distal aspect of the T3 bone, and proximal aspect of the MT3 bone at the midline ($P \leq 0.021$). For high-intensity race training, dorsal SCB thickness was significantly greater than plantar at all proximal to distal locations ($P \leq 0.010$). There was not a significant difference between dorsal and plantar SCB thickness for treadmill and horse-walker exercise, although dorsal SCB thickness tended to be larger than plantar overall.

**DISCUSSION**

The results of this study support the hypothesis that high-intensity exercise is associated with greater SCB thickness than low-intensity exercise and is site specific relative to the level of induced strain. The proximodistal and mediolateral SCB thickness patterns varied between groups, supporting our hypothesis that different exercise types and intensities would lead to different SCB thickness patterns.

An increase in SCB thickness is likely to be related to increased magnitude and number of strain cycles in bone of horses undergoing high- compared with low-intensity exercise. This supports findings from other studies investigating the effect of strenuous training on bone (23, 31). The response of cortical bone to loading is strain rate dependent (20). In the galloping horse, bone experiences strain rates in excess of those recorded for any other species (12). Horses in race training undergo more galloping than in other types of training, leading to high-impact forces and a high rate of strain. Therefore, it was not surprising that in the present study, high-intensity race training was associated with thicker SCB than low-intensity exercise (GP or horse walker). Elite competition was also associated with significantly thicker SCB than low-intensity exercise, although to a lesser degree than race training. Horses undergoing elite competition training are likely to experience more intensive training than GP horses and would be likely to experience greater compressive strain in the tarsus associated with jumping higher (38) or sustaining increased degree and duration of tarsal compression in dressage (16). As elite competition horses are unlikely to be undertaking galloping training (dressage horses) or will be galloping at slower speeds for a shorter duration (event horses) compared with the race training group, the bone is likely to experience lower impact and lower strain rate than horses in race training, which could explain the lesser degree of increase in SCB thickness with elite competition than race training.

In contrast to over-ground race training and elite competition, high-intensity treadmill training was not associated with increased SCB thickness relative to low-intensity exercise. This could be related to difference in age or training duration between the groups as the treadmill training duration was only 19 wk in 2-yr-old horses compared with longer-term race training in older horses. Horses reach skeletal maturity when the last growth plates of the appendicular skeleton close at ~4 yr of age (18), so it is possible that differences in SCB thickness could be related to a cumulative effect of loading with age (2). However, difference in gait between treadmill and over-ground training could have influenced the findings, relating to both overall thickness of SCB and pattern of SCB thickness across the articular surfaces. In humans, tibial compressive and tensile strain and strain rates were significantly greater during over-ground running than treadmill exercise (21), which would be supported by the thicker SCB in horses trained over ground, suggesting greater strain and strain rates than treadmill exercise. If the hindlimbs are not being used to propel the horse forward with the same force as they would over ground, the strain intensity would be relatively reduced and distribution altered. Differences have been established between the kinematics of horses exercised on a treadmill compared with those exercised over ground, with an increased stance duration, more caudal movement of limbs during retraction, and less vertical movement of the hooves during treadmill exercise (4). Treadmill exercise has been associated with increased congruency of other joints (19), which could potentially alter load distribution (10) and SCB thickness across the
articular surfaces and may relate to exercise in a straight line, leading to more even strain distribution across the articular surfaces. Other factors that were likely to have affected loading across the tarsus include the difference in treadmill surface to over-ground training, which can affect loading of the limbs (17), the incline of the treadmill (horses in the present study worked at a 3% incline), and the lack of rider influence.

Although there was generally greater SCB thickness dorsally for all groups, this difference was maximal for elite competition and race training. The increased dorsal SCB in these exercise groups indicates that the dorsal aspect is experiencing greater strain than in low-intensity exercise. This supports the findings of a previous study in which there was a greater dorsal-to-plantar ratio of radiopharmaceutical uptake in elite showjumping horses than in GP horses (26). This dorsal increase could relate to the increased duration of tarsal compression experienced by both elite dressage (16) and jumping (38) horses and compression sustained in galloping. This could potentially predispose the dorsal aspect to repetitive overloading. Clinically, osteoarthritic change is reported to start on the dorsal aspect (6).

Both proximal to distal and medial to lateral variations between groups were present. In a previous study (3), a process for transfer of maximum compressive load from the proximal medial aspect of the tarsus to the distal lateral aspect of the tarsus was suggested. In the present study, variation in patterns between groups reflects the possibility of different gaits and exercise intensities, leading to altered transfer of load through the tarsus from proximal medial to distal lateral. Low-intensity exercise horses had increased SCB thickness on the lateral aspect, while in elite competition centrodorsal joint SCB thickness was greater medially than laterally and tarsometatarsal joint SCB thickness was greater laterally than medially; in horse-walker exercise, medial and lateral were greater than midline, and for race training and treadmill exercise horses there was a less distinct mediolateral pattern. These results illustrate that the tarsus is subjected to different patterns of loading in the different exercise groups. The pattern of loading in the joints of elite competition horses and horse-walker exercise could be affected by working on a circle for a high percentage of time compared with race or treadmill training, which is primarily done in straight lines or straight lines with very large curves in the United Kingdom. Compressive strain in the third metacarpal bone is increased on the lateral aspect in the inside limb and the medial aspect of the outside limb during turning (7). Although the biomechanics of loading may be different in forelimbs and hindlimbs, it could be extrapolated that working on a circle may lead to greater compressive strain laterally in the inside tarsus and medially in the outside tarsus. This could provide an explanation for the patterns seen in both horse-walker exercise and elite competition exercise.

As horse-walker exercise was performed in a circle in both directions, both medial and lateral aspects of the limbs would have been subject to increased compressive strain, and hence increased SCB thickness at these sites, with little strain on the midline. For elite competition exercise, it is possible that the pattern observed is related to turns and circles at faster speeds, or related to the specific movements required, such as sideways movements and turns around a single hindlimb carrying the body weights of both the horse and rider (pirouettes). In gaits performed during elite level dressage competition, such as passage, piaffe, and pirouettes, the tarsal joint is required to flex more than in other gaits (5, 16). These movements are unlikely to be undertaken by GP horses or racehorses. It is possible that for elite jumping, tarsal compression required at takeoff and landing and the sharp turns between fences could alter the proximal to distal pattern of loading in a similar way.

Anecdotal clinical experience and a recent study indicate that flat-race horses have reduced risk of distal tarsal osteoarthritis compared with GP or competition horses (25). It may be that the pattern of tarsal loading during race training is protective against the development of tarsal osteoarthritis. It is therefore possible that using training in straight lines during management of competition and GP horses with very early tarsal pain could simulate these loading patterns and potentially limit progression.

This study had a number of limitations. There were limited numbers in each group and age variation between the groups. Although these were taken into account in the statistical analysis, the findings should still be interpreted in this light. It should also be taken into account that two horses in the elite competition group were not in elite level work at the time they were euthanized, having recently been restricted to box rest and controlled walking exercise. Despite this reduction in activity, joints from horses in this group still had a proximal-to-distal SCB thickness pattern consistent with the remainder of the group, suggesting that established changes to SCB thickness remain unchanged for at least 6 wk after a reduction in exercise. In rats restricted to cages for 15 wk following 15 wk running on a treadmill, structural properties of SCB remained unchanged, but material properties returned to control level quickly (14).

In conclusion, SCB thickness in the distal aspect of the equine tarsus is affected by both exercise intensity and type. Different types of high-intensity exercise were associated with different patterns of SCB thickness across the joints from medial to lateral and proximal to distal, indicating that both exercise intensity and type of exercise affect the SCB response at any particular site within a joint.

GRANTS

We thank the Pet Plan Charitable Trust, the Horse Trust, and the Barbinder Trust for funding of the low-intensity and elite competition exercise portion of the study, and the Horserace Betting Levy Board for background funding in association with the high-intensity race training, treadmill exercise, and horse-walker exercise part of the study.

REFERENCES

EFFECT OF EXERCISE ON THE DISTAL TARSUS


