

Title

A comparison of haemolytic responses in fore-foot and rear-foot distance runners.

Running Title

Foot-strike and haemolysis.

Authors

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Key Words: Haemolysis; Running Technique; Iron

Abstract

This study examined the haemolytic effects of an interval-based running task in fore-foot and rear-foot striking runners. Nineteen male distance runners (10 fore-foot, 9 rear-foot) completed 8 x 3 min repeats at 90% $\dot{V}O_{2\text{peak}}$ on a motorised treadmill. Pre- and post-exercise venous blood samples were analysed for serum haptoglobin to quantify the haemolytic response to running. Vertical ground reaction forces were also captured via a force plate beneath the treadmill belt. Haptoglobin levels were significantly decreased following exercise ($p=0.001$) in both groups (but not between groups), suggesting the running task created a haemolytic stress. The ground reaction force data showed strong effect sizes for a greater peak force ($d=1.20$) and impulse ($d=1.37$) in fore-foot runners, and a greater rate of force development ($d=2.74$) in rear-foot runners. The lack of difference in haptoglobin response between groups may be explained by the trend for fore-foot runners to experience greater peak force and impulse during the stance phase of their running gait, potentially negating any impact of the greater rate of force development occurring from the rear-foot runners' heel strike. Neither type of runner (fore-foot or rear-foot) appears more susceptible to technique related foot-strike haemolysis.

Key Words: Haemolysis; Running Technique; Iron

Introduction

Exercise-induced haemolysis has been demonstrated in weight bearing activities such as running, largely attributed to the impact forces that occur during ‘heel-strike’ (Telford et al., 2003). Previously, a force-dependent relationship between foot-strike and haemolysis has been proposed, such that a greater haemolytic reaction was recorded after running downhill (where the impact forces are greater), as compared to uphill (Miller, Pate, & Burgess, 1988). To this end, it appears intuitive that reducing the impact of foot contact during running may potentially reduce the haemolysis incurred.

One strategy to reduce the impact forces associated to foot-strike in runners has recently seen a trend for athletes to alter their habitual foot-strike pattern, from rear-foot to fore-foot, with the suggested benefit of increasing running efficiency, and possibly decreasing injury rates (Lorenz & Pontillo, 2012). A common hypothesis for why fore-foot is promoted over rear-foot running is to reduce the sharp peak impact forces (i.e. the heel-strike transient) that typically occur in rear-foot runners, which are absent in a fore-foot running technique (Cavanagh & LaFortune, 1980). Recently, it was suggested that fore-foot runners generate smaller collision forces during ground contact due to the absence of a heel-strike transient (Lieberman et al., 2010). However, although it is evident that rear-foot runners exhibit a greater rate of force production as a result of their heel-strike, it is unclear as to the impact this may have on the haemolytic response to a given running task.

Therefore, this study investigated the influence of habitual foot-strike pattern on haemolysis in distance runners. It was hypothesised that, following a bout of high intensity aerobic running intervals, rear-foot runners will show greater post-exercise haemolysis when compared to fore-foot runners. Additionally, a secondary hypothesis was that rear-foot runners will present with lower iron stores as a result of a cumulative haemolytic stress experienced from their training program.

Methods

Participants

This study recruited 19 well-trained male distance runners (10 fore-foot and 9 rear-foot; Table 1). Athletes were recruited from local distance running clubs and training squads. Inclusion criteria required participants to be male, aged 18-38 years, who were consistently training and racing, with an ability to run sub-36 min over 10 km. This performance level was confirmed with a season best 10 km race time (Table 1). Prior to commencing any experimental trials, all participants signed a declaration of informed consent. This study was approved by the Human Ethics Committee of the host institution, adhering to the declaration of Helsinki (64th WMA General Assembly, Fortaleza, Brazil, October 2013).

Experimental Overview

Participants attended two separate exercise sessions as part of this investigation. All testing was conducted at the same time of day to avoid any influence of circadian variation. Each session was separated by approximately one week. Session 1 included a treadmill-based graded exercise test to exhaustion, in order to obtain a measure of peak oxygen consumption ($\text{VO}_{2\text{peak}}$). The running speed for the subsequent session was derived as a percentage of the peak speed achieved during the graded exercise test ($v\text{VO}_{2\text{peak}}$). Session 2 commenced with a 10 min treadmill warm-up performed at 65% $v\text{VO}_{2\text{peak}}$, and 5 min of dynamic stretches. Next participants completed an interval running session involving 8 x 3 min repeats at 90% $v\text{VO}_{2\text{peak}}$ on a work-to-rest ratio of 2:1. The recovery periods encompassed 90 s of active-recovery at 5 $\text{km}\cdot\text{h}^{-1}$. This particular interval running protocol was adapted from previous research conducted in our laboratory, which has shown a significant haemolytic responses to the type of work completed here (Badenhorst et al., 2015; Badenhorst et al., 2014; Sim et al., 2013). Furthermore, interval running training has been shown to result in a greater haemolytic response as compared to a distance matched, low intensity continuous run (Peeling et al., 2009). Heart rate and ratings of perceived exertion were collected after each 3 min effort, and were averaged for the entire trial. Blood lactate was measured at the completion of the trial. Subsequent to the eighth 3 min repetition, participants were immediately moved to an instrumented treadmill where they completed a final 60 s

effort, again at a pace of 90% $v\dot{V}O_{2peak}$. Here, vertical ground reaction forces over six consecutive foot-strikes were captured after 30 s, in order to represent the typical vertical ground reaction force encountered throughout the interval session, when under fatigue. Subsequently, a 5 min cool-down was commenced at 65% $v\dot{V}O_{2peak}$. During session 2, forearm venous blood samples (8.5 mL) were taken 30 min pre- and 30 min post-exercise, each after 10 min of supine rest. Fluid intake was standardised throughout the trial, and included; 200 ml of water in the 30 min pre-exercise, 50 ml after repetitions 3 and 6, and 600 ml of Powerade (Coca-Cola Ltd., AUS) at the completion of the session. For both the graded exercise test and the interval session, participants were instructed to wear the same training shoe on each occasion (Table 1). Finally, all participants were instructed not to consume alcohol or caffeine for 24 h prior, and to abstain from consuming any food for at least 2 h prior to each testing session. In an attempt to quantify food intake, participants were asked to provide a written food inventory for the 12 h prior to session 2. This written food inventory was subsequently analysed using FoodWorks® software (FoodWorks® Professional 2007, Version 5).

Experimental Procedures

Graded Exercise Test

The graded exercise test was conducted on a motorised treadmill (VR3000, NuryTech Inc., Japan) using 3 min exercise and 1 min rest periods. The initial speed was set at 12 $\text{km}\cdot\text{h}^{-1}$, with subsequent incremental increases of 1 $\text{km}\cdot\text{h}^{-1}$ until voluntary exhaustion. Expired air was analysed for concentrations of O_2 and CO_2 using calibrated Ametek Gas Analysers (Applied Electrochemistry, SOV S-3A/1 and COV CD-3A, Pittsburgh, PA, USA). Ventilation was recorded at 15 s intervals via a calibrated turbine ventilometer (Vacumed Universal Ventilation Meter, 17125, Ventura, CA).

Blood

Venous samples were collected using a 21-gauge needle and 8.5 mL SST Gel separator tube (BD vacutainer, Australia). Samples clotted for 60 min at room temperature, before being centrifuged at 10°C and 3000 rpm for 10 min. The serum supernatant was divided into 1 mL aliquots and stored at -80°C. Frozen serum were batch analysed for pre- and post-exercise circulating levels of haptoglobin, a

common marker of haemolysis; and pre-exercise serum ferritin as a marker of iron stores. Capillary blood samples for blood lactate analysis were collected from the earlobe into a Lactate Pro Analyser (Arkray, Japan).

Serum haptoglobin levels were determined using a Quantikine® enzyme-linked immunosorbent assay (ELISA) kit for human haptoglobin (R&D Systems, Minneapolis, USA). The assay was conducted on a BMG Labtech FLUOstar OPTIMA plate reader. The coefficient of variation for the serum haptoglobin determination of $18.7 \text{ ng}\cdot\text{ml}^{-1}$ and $58.3 \text{ ng}\cdot\text{ml}^{-1}$ was 3.7 and 2.4%, respectively. Serum ferritin levels were determined using an Architect analyser (ISR06055) and a Ferritin Reagent (Abbott Diagnostics, Illinois, USA). The coefficient of variation for ferritin determination at 28.62, 223.05 and $497.85 \mu\text{g}\cdot\text{L}^{-1}$ was 4.58, 4.46 and 4.36 %, respectively.

Heart Rate and Perceived Exertion

A Garmin heart rate monitor (Forerunner 610, Switzerland) continuously measured heart rate over the duration of the two trials. The rating of perceived exertion was recorded using a Borg perceptual scale (Borg, 1982), encompassing the anchor points 6 (very, very light) through 20 (maximal exertion).

Determination of Foot-Strike

Both running sessions were filmed using a high speed video camera (MotionFlow, Sony) to confirm the foot-strike pattern of the athlete in the sagittal plane. Footage was then independently analysed by an experienced biomechanist from the host institution with expertise in running gait analysis. Habitual foot-strike pattern was identified according to the procedures outlined by Sterane et al., (Stearne, Alderson, Green, Donnelly, & Rubenson, 2014). Athletes were classified as habitual fore-foot or rear-foot runners.

Ground Reaction Force Determination

Vertical ground reaction force data was collected using a split belt instrumented treadmill (Bertec Corporation, Columbus OH, USA; 2000Hz). Six consecutive foot contacts from the 60 sec effort at 90% $v\text{VO}_{2\text{peak}}$ were processed using a Matlab script (Matlab, Mathworks Inc., Natick, MA) which time normalised the individual contacts, calculated the peak vertical ground reaction force and peak impact

transient (rear-foot only), and created an average force profile for fore-foot and rear-foot runners. Using non time-normalised data, the impulse (area under the force-time curve) was also calculated. Parameters are presented relative to body mass (kg) and as absolute values. To calculate the rate of loading in rear-foot runners, two time points were selected from the vertical ground reaction force trace; (1) the first frame at which force values exceeded 200 N, and (2) the first frame at which force values exceeded 90% of the peak impact transient magnitude. The change in these values was then considered with respect to time. The abovementioned method was also applied to determine the rate of loading in fore-foot runners; however, due to a lack of impact transient in this group, the second time point mentioned above was determined to occur at a constant percentage of stance phase (8.8%), corresponding to the average stance phase value at which rear-foot runners obtained 90% peak impact transient force values. Such methodology are in accordance with previously published methods (Lieberman et al., 2010; Williams, McClay, & Manal, 2000).

Statistical Analysis

Data are presented as mean and standard deviation (\pm SD), unless otherwise stated. Normality of distribution was assessed *via* a Shapiro-Wilk test, and variance homogeneity assessed *via* Levene's test of equality of error variances. In both instances the null hypothesis was accepted to assume normal distribution and equal variance ($p > 0.05$). A one-way ANOVA was used to calculate main effects for differences in participant characteristics, iron status and ground reaction force outcomes between fore-foot and rear-foot runners. For haemolytic data, a repeated measures ANOVA (with foot-strike as the fixed effect) for time and interaction effects was employed. Post-hoc, Fishers LSD tests were used as a follow-up in the event of a main effect. Statistical significance was set at $p < 0.05$. Effect sizes (Cohen's *d*) were calculated and interpreted using a modified Cohen effect size scale (Hopkins, Marshall, Batterham, & Hanin, 2009) as either trivial (< 0.2); small (0.2-0.6); moderate (0.6-1.2); large (1.2-2.0); or very large (2.0-4.0). Only large effect sizes are presented here. In order to examine any relationship between ground reaction force and haemolysis, a Pearson's correlation coefficient was calculated between the change in serum haptoglobin (pre- to post-exercise) and the ground reaction force variables outlined above for both the rear-foot and the fore-foot running groups.

Results

Participants, Shoes and Nutrition

Participants' anthropometric and physiological characteristics, season best 10 km race time, and the characteristics of the shoes worn on each testing day (i.e., shoe age, usage and weight) are shown in Table 1. No significant differences were noted for any of these variables between the fore-foot or rear-foot groups ($p > 0.05$). Analysis of the 12 h food inventory collected prior to session 2 showed no significant difference between groups with respect to carbohydrate (fore-foot: 113 ± 63 g; rear-foot: 107 ± 89 g; $p = 0.876$), protein (fore-foot: 32 ± 24 g; rear-foot: 33 ± 38 g; $p = 0.958$), fat (fore-foot: 30 ± 20 g; rear-foot: 19 ± 13 g; $p = 0.174$) or total energy (fore-foot: $3,617 \pm 1,790$ kJ; rear-foot: $3,117 \pm 2,117$ kJ; $p = 0.596$) intake.

Baseline Iron Status

Baseline analysis of iron status showed that 80% of the fore-foot group, and 88% of the rear-foot group had serum ferritin levels considered healthy ($>35 \mu\text{g}\cdot\text{L}^{-1}$; (Peeling et al., 2007)). There were no significant differences found in the mean serum ferritin levels of the two groups (fore-foot: $67.7 \pm 39.1 \mu\text{g}\cdot\text{L}^{-1}$, rear-foot: $67.9 \pm 27.2 \mu\text{g}\cdot\text{L}^{-1}$; $p = 0.986$).

Interval Running Session

No significant differences were recorded between the groups mean heart rate (rear-foot: 170 ± 6 bpm; fore-foot: 165 ± 15 bpm; $p = 0.188$), rating of perceived exertion (rear-foot: 14 ± 1 ; fore-foot: 13 ± 2 ; $p = 0.620$), or post-exercise blood lactate (fore-foot: $2.5 \pm 1.3 \text{ mmol}\cdot\text{L}^{-1}$; rear-foot: $2.3 \pm 1.3 \text{ mmol}\cdot\text{L}^{-1}$; $p = 0.310$) during the interval running sessions. However, indicative of a relative fatiguing effect created by the interval running task, the combined groups heart rate and rating of perceived exertion did significantly increase from interval repetition 1 to 8 (161 ± 15 to 168 ± 16 bpm, $p = 0.035$; and 13 ± 1 to 14 ± 1 , $p = 0.0001$, respectively), as did the pre- to post-exercise blood lactate (0.8 ± 0.6 to $2.3 \pm 1.3 \text{ mmol}\cdot\text{L}^{-1}$, $p = 0.0001$).

Haemolytic Stress

A significant time ($p=0.001$) effect showed serum haptoglobin was lower after the interval session (Figure 1). This reduction in haptoglobin occurred in both the fore-foot ($p=0.001$) and the rear-foot ($p=0.049$) groups, but was not different between conditions ($p=0.902$).

Foot-Strike Characteristics

Figure 2 shows the mean absolute ground reaction force of the fore-foot and rear-foot groups. No significant differences were seen in peak force (fore-foot: 1780.52 ± 312.65 N; rear-foot: 1495.08 ± 348.17 N; $p=0.118$) or impulse (fore-foot: 211.18 ± 30.42 N·s; rear-foot: 181.66 ± 46.45 N·s; $p=0.519$) between the two groups. Strong effect sizes suggested a trend for the fore-foot runners to have a greater peak force ($d=1.20$) and impulse ($d=1.37$) than rear-foot runners. Similar results were seen when ground reaction force was standardised to body mass; no significant differences were seen in peak force (fore-foot: 2.59 ± 0.36 N·kg⁻¹; rear-foot: 2.24 ± 0.51 N·kg⁻¹; $p=0.143$) or impulse (fore-foot: 0.31 ± 0.03 N·s·kg⁻¹; rear-foot: 0.27 ± 0.06 N·s·kg⁻¹; $p=0.150$) between conditions, but strong effect sizes suggested a trend for the fore-foot runners to have a greater peak force ($d=1.32$) and impulse ($d=1.58$) than rear-foot runners. The peak vertical ground reaction force of the heel-strike transient in the rear-foot group was 1141 ± 288 N. When the rate of force development to the peak of the heel strike transient in the rear-foot group (90.85 ± 45.75 kN·s⁻¹) was compared to the same percentage of stance phase in the fore-foot group (61.63 ± 7.34 kN·s⁻¹), no significant differences were found ($p=0.112$); however, strong effect sizes suggested a trend for the rear-foot runners to have a greater rate of loading ($d=2.74$) than fore-foot runners during this phase of stance.

Correlations

Pearson's correlation coefficients for the relationship between the change in serum haptoglobin and the ground reaction force data for each group are presented in Table 2. A significant ($p<0.05$), strong positive correlation was found between the relative peak ground reaction force and the change in serum haptoglobin in the rear-foot running group. No further significant correlations existed.

Discussion

The primary aim of this study was to determine the influence of habitual rear-foot and fore-foot running techniques on haemolysis in distance runners. Secondly, we also sought to investigate if running technique was associated with an athlete's iron status. Our results indicate that a significant haemolytic stress was incurred following a bout of high intensity aerobic running intervals, as reflected by the significant decrease in post-exercise serum haptoglobin across both groups. However, this exercise-induced haemolysis was not significantly influenced by foot-strike pattern, which also does not associate to the runners' baseline iron status.

Previously, a number of investigations have explored the haemolytic response to various exercise protocols (Miller et al., 1988; Peeling et al., 2009; Telford et al., 2003). This research demonstrated that haemolysis occurs during both weight supported (i.e. swimming and cycling) and non-weight supported (i.e. running) exercise (Miller et al., 1988; Selby & Eichner, 1986). However, when an intensity and duration-matched (60 min at 75% $\text{VO}_{2\text{peak}}$ intensity) bout of running was compared to cycling, the haemolytic response was found to be four-fold greater in the running trial (Telford et al., 2003). The greater haemolytic stress was attributed to the impact forces incurred at foot-strike, which were absent during cycling. Such outcomes supported the findings of Miller et al., (Miller et al., 1988) who observed significantly more haemolysis during downhill running (-6% treadmill gradient) when compared with an equivalent speed uphill run (+6% treadmill gradient). These authors also suggested that the mechanical trauma incurred at foot-strike was the primary cause of haemolysis during running, since the loads encountered during downhill running were suggested to be ~11% greater than an uphill equivalent (Miller et al., 1988). Finally, Peeling et al., (Peeling et al., 2009) showed a greater haemolytic response when high intensity interval-based running was compared to a distance matched (10 km), continuous low intensity effort. These authors attributed the haemolytic differences to the increased exercise intensity of the interval running trial; suggesting that the combination of an increased ground reaction force and an increase in step cadence when running at higher intensities might explain the greater red blood cell destruction. Clearly, the collective outcomes of this previous research suggests that as the impact forces incurred during running increase, so does the magnitude of the resultant haemolysis.

Since it was recently established that fore-foot runners generate smaller initial collision forces than rear-foot runners due to a more plantar-flexed foot at landing and more ankle compliance during impact (Lieberman et al., 2010), it was hypothesised that fore-foot runners might experience less haemolysis at the conclusion of a standardised running session, likely due to the aforementioned relationship between impact forces and red blood cell destruction. Although our data show a stronger relationship between the change in serum haptoglobin and the relative peak ground reaction force in the rear-foot group, there were no differences evident in the relative peak ground reaction forces between the two conditions, nor were there any differences between the magnitude of haemolytic stress incurred by either running technique.

One possible explanation for the absence of any differences in haemolysis between the fore-foot and rear-foot running groups may exist in their respective vertical ground reaction force profiles. These results show a strong effect for rear-foot runners to have a greater rate of loading during the initial ground contact phase (i.e. the heel-strike transient), which might have been expected to result in a greater degree of haemolysis. However, this may have been off-set by the strong effect for a greater peak force and impulse in the vertical ground reaction force profile of the fore-foot runners. Such outcomes might be supported by the prior findings of Stearne et al., (Stearne et al., 2014) who showed that lower limb work and average power did not differ between habitual rear-foot and fore-foot runners, but that the moments, negative work and negative instantaneous and average power during stance were greater at the knee in rear-foot runners, and at the ankle in fore-foot runners. These authors concluded that no clear overall mechanical advantage was likely from habitual fore-foot or rear-foot running techniques as a result of the altered distribution in loading between joints (Stearne et al., 2014). With this in mind, the strong effect sizes that suggest differences in vertical ground reaction forces at different stages of the stance phase between the rear-foot and fore-foot runners of the current investigation may also point to an altered distribution of force relative to the running technique, ultimately resulting in the same haemolytic outcome due to a similar overall load encountered.

Our secondary hypothesis was that rear-foot runners would present to our laboratory with lower iron stores than their fore-foot counterparts as a result of a cumulative haemolytic stress experienced from

their training program. Previously, it has been suggested that although a single haemolytic episode may not result in significant iron losses, a cumulative effect of haemolysis may exist when successive training sessions are performed, which may ultimately lead to depleted iron stores if not adequately replaced by the diet (Peeling et al., 2009). Despite our hypothesis, the baseline iron status for the athletes of this investigation showed that 80% of fore-foot runners, and 88% of rear-foot runners presented with healthy serum ferritin levels ($>35 \mu\text{g}\cdot\text{L}^{-1}$; (Peeling et al., 2007)), with no differences in the mean serum ferritin reported between groups. Such an outcome in the context of the hypothesis is likely not surprising given that neither foot-strike pattern resulted in a significantly greater amount of haemolysis. Regardless, these results do suggest that three athletes did present with compromised iron stores. It is well established that exercise leads to an increase in the iron regulatory hormone, Hepcidin (Peeling, 2010). One particular action of Hepcidin is to internalise and degrade the ferroportin iron export channels on the surfaces of macrophages (Nemeth et al., 2004). When considered in the context of exercise-induced haemolysis, it is possible that red blood cell senescence cleaned up by the macrophage may have its iron rendered within the cell due to the deterioration of the export channels by which iron is recycled. Since collectively this cohort of athletes all reported a haemolytic response to the running task, the interrelationship between haemolysis and iron metabolism cannot be ignored, and should be considered in future research.

Limitations

Despite the outcomes of this investigation, some limitations might be considered and explored in future research. Firstly, the quantification of vertical ground reaction force data was only possible for a short time period at the end of our interval running session. Over the course of a training bout, fatigue may cause a degeneration in running technique, and as such, the running loads encountered at the beginning of the session may have been different. However, given the loads here were quantified under fatigue, it is likely that we were able to capture the greatest loads encountered during the interval running task. Regardless, future research might attempt to capture ground reaction force data over the entire duration of the exercise session. Secondly, the cohort investigated here was relatively homogenous based on athletic standard; however, there may be some between athlete variation in the average running stride-

length and number of ground contacts incurred throughout the session. Such variation may have an impact on the degree of haemolysis incurred. In addition, acute exercise-induced changes in plasma volume were not quantified here, and as a result, the magnitude of the post-exercise reductions in haptoglobin may have been marginally greater across both groups in the event of a plasma volume reduction. Finally, it might also be considered that the type of shoe worn by each athlete, and the food consumption during the 12 h period prior to testing was not controlled here. Although there were no between group differences in shoe age, use or weight, it was not possible to quantify the degree of cushioning provided within each shoe. Although controlling for the shoe type would be very difficult (as a result of individual gait variability and shoe preference), the use of a standardised shoe in future investigations would be welcomed. Furthermore, although there were no differences in the macronutrient content or energy intake of the two groups' nutritional practices prior to session 2, further consideration of acute carbohydrate intake might be warranted due to the well-known influence of glycogen stores on inflammatory processes (Steensberg et al., 2001), which may have implication to haemolytic outcomes.

Conclusion

This study shows that both habitual fore-foot and rear-foot running techniques experience haemolysis of an equivalent magnitude following a bout of high intensity interval running. It is possible that the lack of difference between the fore-foot and rear-foot running groups was due to an altered distribution of force throughout stance, relative to the running technique, which in effect off-set any potential greater rate of force development from a heel-strike transient in rear-foot runners. It was also shown that there a runner's habitual foot-strike pattern does not seem to influence their iron status.

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Table 1. Mean (\pm SD) age, body mass, season best 10 km race time, peak oxygen consumption (VO_{2peak}), speed at VO_{2peak} (vVO_{2peak}), interval speed (90% vVO_{2peak}) and shoe characteristics for the fore-foot (FF) and rear-foot (RF) groups.

Group	Age	Body Mass	Season Best 10 km Race Time	VO_{2peak}	vVO_{2peak}	90% vVO_{2peak}	Shoe Characteristics		
	(y)	(kg)	(min)	($mL \cdot kg^{-1} \cdot min^{-1}$)	($km \cdot h^{-1}$)	($km \cdot h^{-1}$)	Age (months)	Use (km)	Weight (g)
FF	24.3	69.7	34.47	73.16	19.3	16.6	6	202	218
	(± 6.7)	(± 6.5)	(± 1.71)	(± 3.04)	(± 1.1)	(± 1)	(± 5)	(± 154)	(± 58)
RF	22.9	66.4	34.25	70.71	19.7	16.9	7	199	235
	(± 4.5)	(± 7.5)	(± 1.35)	(± 3.92)	(± 1.2)	(± 1.5)	(± 6)	(± 158)	(± 66)

Table 2. Pearson's correlation coefficient (r) between the change in serum haptoglobin (pre- to post-exercise) and the ground reaction force variables for the fore-foot (FF) and rear-foot (RF) running groups.

	Change in Serum Haptoglobin (g·L⁻¹)	
	FF	RF
Peak Force (N)	0.00	0.60
Relative Peak Force (N·kg⁻¹)	0.02	0.81*
Impulse (N·s)	-0.13	0.35
Relative Impulse (N·s·kg⁻¹)	-0.15	0.59
Rate of Force Development (kN·s⁻¹)	-0.15	-0.24

* Significant correlation ($p \leq 0.05$)

Figure Legend

Figure 1: Mean (\pm SEM) serum haptoglobin (Hp) recorded pre- and post- the interval running trial, and the pre- to post- change values, for the fore-foot (FF) and rear-foot (RF) running groups.

‡ Significantly different to baseline ($p \leq 0.05$).

Figure 2: Average absolute vertical GRF curve of six consecutive foot-strikes for each runner in (A) the fore-foot (FF) running group, and (B) the rear-foot (RF) running group.



