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Effect of the coefficient of friction of a running surface on sprint time in a sled-towing exercise

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Abstract

This study investigated the effect of the coefficient of friction of a running surface on an athlete's sprint time in a sled-towing exercise. The coefficients of friction of four common sports surfaces (a synthetic athletics track, a natural grass rugby pitch, a 3G football pitch, and an artificial grass hockey pitch) were determined from the force required to tow a weighted sled across the surface. Timing gates were then used to measure the 30-m sprint time for six rugby players when towing a sled of varied weight across the surfaces. There were substantial differences between the coefficients of friction for the four surfaces (μ = 0.21–0.58), and in the sled-towing exercise the athlete's 30-m sprint time increased linearly with increasing sled weight. The hockey pitch (which had the lowest coefficient of friction) produced a substantially lower rate of increase in 30-m sprint time, but there were no significant differences between the other surfaces. The results indicate that although an athlete's sprint time in a sled-towing exercise is affected by the coefficient of friction of the surface, the relationship between the athlete's rate of increase in 30-m sprint time and the coefficient of friction is more complex than expected.

Introduction

Sled-towing is a common training exercise for developing sprint-specific strength in track and field athletics and in field sports such as rugby league, rugby union, American football, Australian rules football, and soccer (Faccioni, 1994; Seagrave, 1996; Sheppard, 2004; Spinks et al., 2007; Harrison & Bourke, 2009). In a sled-towing exercise, the load on the athlete arises mainly from the friction force between the base of the sled and the running surface (Cronin & Hansen, 2006). The magnitude of this force is given by the product of the normal force of the sled and the coefficient of kinetic friction for the combination of sled and running surface (Halliday et al., 2001). If the running surface is level and the tow cord is held at a constant angle, then the normal force of the sled is proportional to the weight of the sled. When using sled-towing exercises, many coaches set the weight of the sled as a percentage of the athlete's body weight so as to account for the fact that larger athletes tend to have greater muscular strength and can generate greater muscular power. Several studies have shown that towing a weighted sled reduces the athlete's running velocity, stride length, and stride frequency; increases the ground contact time; increases the forward lean of the trunk; and produces changes in the configuration of the athlete's lower limbs during the ground contact phase of the stride (Lockie et al., 2003; Murray et al., 2005; Alcaraz et al., 2008; Cronin et al., 2008; Maulder et al., 2008). The magnitudes of these changes tend to increase with increasing sled weight and some coaches recommend an upper limit to the weight of the sled so that the exercise does not induce excessive changes in the athlete's sprinting technique (Jakalski, 1998; Mouchbahani et al., 2004; Cissik, 2005; Alcaraz et al., 2008; Maulder et al., 2008).

Although considerable work has been done on the biomechanics of sled-towing exercises, the influence of the coefficient of friction of the running surface on the athlete's running velocity and sprint time has not received adequate attention. If a sled-towing exercise is performed on different running surfaces (with different coefficients of friction), a substantially greater or lesser sled weight should be required in order to produce the same training stimulus. However, the strength of the relationship between the coefficient of friction of a running surface and the athlete's sprint time in a sled-towing exercise is currently not known. Knowledge of this relationship could help coaches to evaluate the intensity of the exercise and so help determine the most appropriate sled weight for the athlete.

A simple energy argument suggests that as the coefficient of friction of the running surface increases the athlete's sprint time in a sled-towing exercise should increase because more of the athlete's muscular power is dissipated through sled friction. Therefore, we expect that running surfaces with a higher coefficient of friction should produce a greater rate of increase in the athlete's sprint time with increasing sled weight. A complicating factor in any investigation of sled-towing exercises is that athletes can differ in their physical capacities and sprinting technique. On any given running surface we might expect to observe inter-athlete differences in the strength of the relationship between sprint time and the weight of the sled, and when comparing running surfaces we might expect to observe inter-athlete differences in the strength of the relationship between the athlete's rate of increase in sprint time with increasing sled weight and the coefficient of friction of the running surface.

In the study reported here, we measured the coefficient of friction for a sled sliding across four common sports surfaces (a synthetic athletics track, a natural grass rugby pitch, a 3G football pitch, and an artificial grass hockey pitch). We then measured the 30-m sprint times of six rugby players when towing a weighted sled on the four surfaces. The main hypothesis of the study was that the strength of the relationship between 30-m sprint time and sled weight would show a steadily increasing trend as the coefficient of friction of the surface increased. The two secondary hypotheses were that on any given sports surface there would be substantial inter-athlete differences in the strength of the relationship between 30-m sprint time and sled weight, and that there would be substantial inter-athlete differences in the strength of the relationship between the rate of increase in 30-m sprint time and the coefficient of friction of the sports surface.

Methods

Coefficient of friction of selected sports surfaces

We used the 'friction sled' method of determining the coefficient of kinetic friction for a body sliding over a flat surface (Blau, 1996; Persson, 1998). In this method, a normal force (N) is applied to the body and the tangential towing force (F) required to move the body at constant velocity across a (fixed) flat surface is measured. The gradient of the (linear) relation between the normal force and the tangential towing force gives the coefficient of kinetic friction (i.e. $F = \mu N$). In the present study, we tested a sports training sled when sliding over four common sports surfaces: a Rekortan M99 athletics track (APT Corp., Harmony, PA, USA), a Top Blade 3G artificial grass football pitch (Blakedown, Banbury, Oxfordshire, UK), a Blakedown Elite artificial grass hockey pitch (Blakedown, Banbury, Oxfordshire, UK), and a natural grass rugby pitch. The sled had a mass of 3.3 kg and a series of weights were added to the sled, giving a total mass of up to 55 kg. The sled was towed by hand at a constant velocity of about 0.5 m/s while the towing force on the sled was measured with a spring balance. The sled travelled on two parallel metal tubes about 550 mm long and 25 mm in diameter, and the sliding surfaces of the base of the sled were smooth bare steel. When towing the sled, the towing force and spring balance were horizontal to within about 5°. The coefficient of friction (μ) for the sled-surface combination was obtained from the gradient of a least-squares linear fit to a plot of the towing force against sled weight.

For many combinations of materials, the coefficient of kinetic friction has little or no dependence on the velocity of sliding, the area of contact between the surfaces, or the surface roughness of the materials (Blau, 1996; Persson, 1998). However, in this study we tested for velocity dependence in the coefficient of friction by towing the sled across the Rekortan athletics track at various speeds. The sled was loaded with a series of weights and five trials were conducted at each weight using velocities between about 0.5 m/s and 2.5 m/s. Two timing gates with a time resolution of 0.001 s were placed 2.0 m apart and the velocity of the sled was calculated from the elapsed time obtained from the two gates. A multivariate linear regression analysis using the forced entry method was used to determine the relative contributions of the sled weight and towing velocity to the friction force. The analysis was conducted using PASW Statistics 18 (IBM, Somers, NY, USA), the independent variables were the sled weight and the towing velocity, and the dependent variable was the friction force.

Sled-towing sprint times on the sports surfaces

We tested the four sports surfaces for differences in their effect on sprint time in a 30-m sled-towing exercise. Six male rugby players volunteered to participate in the study. The participants were active players with a university rugby team, with an average age of 20 ± 2 years, height 1.82 ± 0.05 m, and body mass 85 ± 9 kg (mean ± SD). The study was approved by the Human Ethics Committee of Brunel University, the participants were informed of the procedures and inherent risks prior to their involvement, and written consent to participate was obtained.

The sprint trials were 30-m sprints at maximum intensity from a standing start. Two timing gates with a time resolution of 0.001 s were placed 30 m apart. The participant commenced from a line 2 m behind the first gate so as to avoid early breaking of the beam of the first gate and his 30-m sprint time was taken as the elapsed time obtained from the two gates. All tests were conducted in still air conditions in an outdoors sports facility, except for the test of the Rekortan athletics track, which was conducted in an indoor athletics stadium. The participants wore their own athletic training clothes (shorts and tee-shirt) and the same shoes for every surface.

The weighted sled was attached to the participant by a 3 m cord and waist harness. Weights were added to the 3.3 kg sled to give a total weight as a desired percentage of the participant's body weight. The sprint conditions were: no sled, 5%, 10%, 15%, 20%, 25%, and 30% of the participant's body weight. Before testing each sports surface, the participant performed a standardized 15-min warm-up routine consisting of jogging, dynamic stretching, and five unloaded sprints over 30 m. The participant also performed three sprints while towing 10%, 20%, and 30% of their body weight to become familiar with towing a sled on the test surface. For the sled-towing trials, the participant performed one trial at each condition and the order of the trials was randomized. A 5-min rest period was given between trials to minimize the effects of fatigue on sprint performance. This rest period is sufficient for full recovery from repeated maximal sprints of short duration (Harris et al., 1976).

In addition to affecting the friction force acting on the sled, the type of running surface was expected to affect the athlete's 30-m sprint time through differences in the stiffness and energy loss of the surface (Stefanyshyn & Nigg, 2000; Brechue et al., 2005). Tukey's HSD test was used to make pairwise comparisons between the unloaded 30-m sprint times on the four sports surfaces ($\alpha = 0.05$), and the size of the differences was expressed using Cohen's *d*. According to Cohen (1988), the thresholds for 'small', 'medium', and 'large' differences are 0.2, 0.5, and 0.8, respectively. To account for any differences in the energy exchange characteristics of the four running surfaces, all further analysis of the 30-m sled-towing times used the participant's time relative to their unloaded sprint time.

The participant's (relative) sprint times were plotted against the weight of the sled (expressed as a fraction of the participant's body weight), and then a linear regression curve ($y = mx + c$) and a quadratic regression curve ($y = ax^2 + bx + c$) were fitted using the Levenberg-Marquardt algorithm. For each model, a corrected Akaike Information Criterion (IAC_c) was calculated from the variance in the regression fit, and the model with the lowest IAC_c value (and hence the highest relative probability of being correct) was selected as the best fit. Assuming that a straight line was confirmed as the best fit, the gradient (m) was taken as the rate of increase in 30-m sprint time (in seconds per body weight) for the participant.

On any given running surface we might expect to observe inter-athlete differences in the rate of increase in 30-m sprint time due to differences in the athlete's physical capacities and sprinting technique. The magnitude of the inter-athlete variation in the rate of increase in 30-m sprint time on a surface was quantified by calculating the coefficient of variation (CV) of the mean rate of increase in 30-m sprint time. In addition, Tukey's HSD test was used to make pairwise comparisons between the six participants and the size of the differences between the participants was expressed using Cohen's *d*.

Differences in the coefficient of friction of the running surfaces were expected to be evident as differences in a participant's rate of increase in 30-m sprint time (*m*). For each participant, pairwise comparisons between the four sports surfaces were made using Tukey's HSD test and Cohen's *d*.

The main aspect of this study was to investigate the form of the relationship between the rate of increase in 30-m sprint time and the coefficient of friction of the sports surface. The participant's rate of increase in 30-m sprint time was plotted against the coefficient of friction of the sports surface and a selection of regression curves were fitted using the Levenberg-Marquardt algorithm. We tested a straight line, $y = mx + c$; an inverted u-shape, $y = a - b(\mathrm{x} - c)^2$; and an exponential rise to maximum, $y = a\,\{1 - \mathrm{Exp}[-b(\mathrm{x} - c)]\}$. Because only four sports surfaces were tested, a calculation of Akaike's Information Criterion could not be used to decide which of these models gave the best fit to the data. Instead, we used a visual examination of the distribution of the residuals and a comparison of the sum of the square of the residuals in the regression fits to decide upon the best regression curve. Inter-athlete differences in the strength of the relationship between the rate of increase in 30-m sprint time and the coefficient of friction of the sports surface were investigated by comparing the values of the fit variables. Pairwise comparisons between the participants were made using Tukey's HSD test and Cohen's *d*.

Results

For all four sports surfaces, the friction force increased linearly with sled weight (Figure 1), and the four sports surfaces had substantially different coefficient of friction values (Table I).

[Insert Figure 1 about here]

[Insert Table I about here]

When towing a sled across the Rekortan athletics track, our measurements showed that the coefficient of friction was independent of the velocity of the sled, at least over the range of velocities that were tested (0.5–2.3 m/s). The multivariate linear regression analysis showed that 98.3% of the variation in the friction force was explained by the weight of the sled (R^2 = 0.983, p < 0.001), and only 0.1% was explained by the towing velocity (R^2 = 0.001, p = 0.09).

Sled-towing sprint times

When sprinting without a sled, the participant's 30-m sprint times were slightly different on each of the four sports surfaces. The fastest unloaded sprint times were achieved on the Rekortan athletics track (mean = 3.91 s; s = 0.25 s), with times on the natural grass rugby pitch, artificial grass hockey pitch, and 3G football pitch about 0.05 s, 0.10 s, and 0.37 s slower, respectively (rugby 3.96 ± 0.24 s; hockey 4.01 ± 0.13 s; football 4.28 ± 0.11 s). The results of the pairwise comparison tests are shown in Table II. The unloaded sprint times on the 3G football pitch were significantly longer than those on the other three surfaces (d = 0.8–1.0), but the differences between the Rekortan athletics track, natural grass rugby pitch, and artificial grass hockey pitch were not statistically significant.

[Insert Table II about here]

For all combinations of participant and sports surface, the participant's 30-m sprint time when towing a weighted sled tended to increase with increasing sled weight. The relationship between 30-m sprint time and sled weight was almost always linear (Figure 2). For 21 out of 24 combinations of participant and sports surface, a linear fit to the sprint time data gave a lower IAC_c value and a higher relative probability of being correct than a quadratic fit. The three instances of quadratic relationships were produced by the same participant (participant 2; on the rugby pitch, 3G football pitch, and hockey pitch), but the deviation from linearity was not substantial (3–9%). Therefore, in this study the gradient of the linear fit (*m*) was taken as the measure of the rate of increase in 30-m sprint time.

[Insert Figure 2 about here]

There was substantial variation among the six participants in their rate of increase in 30-m sprint time (*m*). The coefficient of variation (CV) for the rate of increase in 30-m sprint time was 16%, 13%, 22%, and 24% for the Rekortan athletics track, natural grass rugby pitch, 3G football pitch, and artificial grass hockey pitch, respectively. For the Rekortan athletics track, 11 of the 15 comparisons of pairs of participants showed large significant differences (d = 1.1–2.7). Similar results were obtained for the natural grass rugby pitch (8 large significant differences, d = 1.0–2.9), 3G football pitch (11 large significant differences, d = 1.2–4.8), and artificial grass hockey pitch (10 large significant differences, d = 1.5–4.4).

Comparison of sports surfaces

The mean rates of increase in 30-m sprint time (in seconds per body weight) were 4.6 ± 1.4 (±95% confidence interval) for the Rekortan athletics track, 4.8 ± 1.2 for the natural grass rugby pitch, 4.2 ± 1.8 s for the 3G football pitch, and 1.9 ± 0.9 for the artificial grass hockey pitch (Figure 3). The results of the pairwise comparison tests are shown in Table III. The rate of increase in 30-m sprint time for the hockey pitch was substantially less than those for the other surfaces, but the differences between the Rekortan athletics track, grass rugby pitch, and 3G football pitch were not statistically significant.

[Insert Figure 3 about here]

[Insert Table III about here]

The participant's rate of increase in 30-m sprint time did not show a steadily increasing trend as the coefficient of friction of the sports surface increased (Figure 3). Instead, the participant's rate of increase in 30-m sprint time appeared to reach a plateau or maximum at about $\mu = 0.4$. An exponential rise to maximum was the best fit for four out of the six participants (1, 2, 3, and 5), and an inverted u-shape was a slightly better fit than an exponential rise for two participants (4 and 6). Therefore, in this study the strength of the relationship between the rate of increase in 30-m sprint time and the coefficient of friction of the sports surface was indicated by the asymptotic maximum value (*a*) of the exponential rise fit for Participants 1, 2, 3, and 5, and by the peak value (*a*) of the inverted u-shape fit for Participants 4 and 6.

Although on any given sports surface there were substantial differences between the participants in the rate of increase in 30-m sprint time, the differences were not random. There was a systematic participant effect whereby participants who had a greater than average rate of increase in 30-m sprint time on one surface tended to have a greater than average rate of increase on the other surfaces (Figure 3). For the strength of the exponential rise relationship between the rate of increase in 30-m sprint time and the coefficient of friction of the sports surface, we obtained $a = 5.66 \pm 0.10$, 5.26 ± 0.07, 4.66 ± 0.10, and 4.08 ± 0.03 seconds per body weight

(±95% confidence interval) for Participants 1, 2, 3, and 5, respectively. In the pairwise comparison tests, all six comparisons showed large significant differences (d = 2.7–13.0). For the strength of the inverted u-shape relationship, we obtained a = 4.46 ± 0.57 and 4.16 ± 0.53 seconds per body weight for Participants 4 and 6 respectively. However, the difference between the participants in these values was not significant (d = 0.6).

Discussion and Implications

The four sports surfaces that were tested in this study had substantially different values for the coefficient of friction (μ = 0.21–0.58), and on all four surfaces the participant's sprint time in a 30-m sled-towing exercise increased linearly with increasing sled weight, for a sled weight of up to at least 30% of the participant's body weight. This study confirmed the two secondary hypotheses, but only partly confirmed the primary hypothesis. On each of the four sports surfaces we found substantial inter-athlete differences in the strength of the relationship between 30-m sprint time and sled weight, and we found substantial inter-athlete differences in the strength of the relationship between the rate of increase in 30-m sprint time and the coefficient of friction of the running surface. However, the relationship between the rate of increase in 30-m sprint time and the coefficient of friction of the running surface was not a steadily increasing trend. The hockey pitch (which had the lowest coefficient of friction) produced a substantially lower rate of increase in 30-m sprint time than the other sports surfaces, but there was no difference between the Rekortan athletics track, grass rugby pitch, and 3G football pitch, even though these surfaces had substantially different values of the coefficient of friction.

Our finding that 30-m sprint time increased linearly with increasing sled weight is consistent with the study by Murray et al. (2005). However, in our study we confirmed that the relationship applied to the individual participants in the study, rather than to the mean of a group of participants, as was shown in the study by Murray et al.

In the present study, the participant's rate of increase in 30-m sprint time reached a plateau or maximum value (at a coefficient of friction of about 0.4) rather than showing a steadily increasing trend (Figure 3). This unexpected result might have been due to inaccurate measurements of the coefficient of friction for the natural grass rugby pitch and 3G football pitch. The Rekortan athletics track and artificial grass hockey pitch were both very uniform surfaces and so we believe that the measured values of the coefficient of friction for these surfaces (Table I) were an accurate indicator of the energy losses induced by the sliding of the sled in the sled-towing exercise. In contrast, the natural grass rugby pitch and 3G football pitch were noticeably less even. We suggest that irregularities in these surfaces might have induced vertical pitching of the sled, resulting in greater energy loss and hence a greater effective coefficient of friction. If so, the data shown in Figure 3 need to be re-interpreted. We suggest that the results from the Rekortan athletic track and artificial grass hockey pitch are accurate and show that an athlete's rate of increase in 30-m sprint time steadily increases as the coefficient of friction of the running surface increases. We also suggest that the data points for the natural grass rugby pitch and 3G football pitch are anomalous in that they have been shifted to the left because the measured coefficient of friction value underestimated the energy losses when performing a sled-towing exercise on these surfaces. If this interpretation is correct, we estimate that the effective coefficients of friction for the sled when being towed over the natural grass rugby pitch and 3G football pitch were actually about 0.6 (rather than the measured values of 0.45 and 0.35, respectively).

The friction sled method that was used in the present study is intended for obtaining the coefficient of kinetic friction for two flat surfaces (Blau, 1996). However, the sled used in the present study travelled on two parallel tubes (rather than on a flat base) and two of the sports surfaces had an uneven surface. Even so, if the lengths and curvatures of the sliding surfaces of the sled are large compared to the irregularities in the sports surface, we might expect the friction sled method to give an accurate measure of the coefficient of friction, at least at relatively slow velocities. In the present study, the maximum velocity at which we were able to tow the sled at constant velocity across the sports surface while simultaneously measuring the towing force was about 2.5 m/s. This is substantially lower than the maximum velocity achieved by an athlete in a sled-towing exercise (about 5–9 m/s). If the coefficient of friction values from the natural grass rugby pitch and 3G football pitch in the present study are indeed anomalous, this would suggest that we needed a method of performing the coefficient of friction measurements that better simulated the conditions of the sled during a sled-towing exercise (i.e. fast-moving and possibly pitching up and down).

When towing a sled across the Rekortan athletics track, our measurements showed that the coefficient of friction was independent of the velocity of the sled. This finding agrees with many other studies of sliding friction, which have consistently found that the coefficient of friction of two sliding surfaces is almost independent of the sliding velocity (Blau, 1996; Persson, 1998). However, in the present study we did not test the natural grass rugby pitch, 3G football pitch, or artificial grass hockey pitch and so we cannot exclude the possibility of a velocity dependence of the coefficient of friction for these sports surfaces.

The unexpected relationship between the rate of increase in 30-m sprint time and the coefficient of friction of the sports surface that was observed in this study (Figure 3) might also have been due to the different surfaces inducing changes in the participant's sprint kinematics. When sprinting without a sled, the participant's 30-m sprint times were slightly different on each of the four sports surfaces. The order of the surfaces (from fastest to slowest) were: Rekortan athletics track, natural grass rugby pitch, artificial grass hockey pitch, and 3G football pitch. The time differences between the surfaces were probably due to differences in the stiffness and energy dissipation properties of the surfaces (Stefanyshyn & Nigg, 2000; Brechue et al., 2005). The Rekortan athletics track was the most firm surface and consisted of bonded rubber crumb overlaid on a solid base. Likewise, the natural grass rugby pitch was relatively firm as it consisted of a short grass layer on hard ground. The artificial grass hockey pitch and 3G football pitch were expected to dissipate more of the participant's energy at each footfall due to movement of the participant's foot in the base layer (Lejeune et al., 1998; Alcaraz et al., 2011). Energy dissipation was expected to be more pronounced for the loose rubber crumb in the 3G football pitch than for the sand base in the hockey pitch. Although differences in the stiffness and energy dissipation properties of the surfaces affected the participant's unloaded sprint time, our initial assumption was that these differences would have no effect on the participant's rate of increase in 30-m sprint time with increasing sled weight. However, we cannot exclude the possibility that the sports surfaces induced different sprinting kinematics in the participant and so influenced the relationship between sled weight and 30-m sprint time (in addition to that due to the frictional energy losses in the sled).

Because of the unexpected complex relationship between the measured coefficient of friction and the rate of increase in 30-m sprint time that was observed in the present study, we currently recommend that coaches use a trial-and-error approach to finding the most appropriate sled weight for an athlete to use on any given running surface. The coach should determine the training intensity of the sled-towing exercise by measuring the decrease in the athlete's time from unloaded sprinting, and use their eye or slow-motion video to look for detrimental changes in the athlete's sprinting technique. We advise caution if using published equations to determine the sled weight for an athlete (Lockie et al., 2003; Alcaraz et al, 2009). Such equations were calculated from tests on a specific sled-surface combination. These equations might be useful as a starting point in choosing an appropriate sled weight for an athlete, as long as the sled-towing exercise is performed on a running surface that is similar to that used by the author of the equation.

In this study we observed inter-athlete differences of ±13–24% in the rate of increase in 30-m sprint time with increasing sled weight (on a given running surface). Some coaches recommend setting the weight of the sled to a certain percentage of the athlete's body weight (Mouchbahani et al., 2004). However, the results from the present study suggest that further 'fine-tuning' of sled weight will be necessary if the aim is to give the athletes a similar training intensity.

Practical implications

When selecting the sled weight to be used in a sled-towing exercise, the coach must take into account the coefficient of kinetic friction of the running surface. We recommend a trial-and-error approach to selecting the sled weight for an athlete because performing a measurement of the coefficient of friction at low velocity using the sled friction method might not give an accurate indicator of the energy losses that occur during a sled-towing exercise on the running surface.

Conclusion

This study showed that an athlete's sprint time in a sled-towing exercise is affected by the coefficient of friction of the running surface as well as by the weight of the sled. We found substantial differences in the coefficient of friction for four common sports surfaces (μ = 0.21–0.58), and the athlete's rate of increase in 30-m sprint time with increasing sled weight was substantially different on the hockey pitch compared to the other three surfaces. However, the rate of increase in 30-m sprint time did not increase in proportion to the increase in the coefficient of friction of the surface. Further studies should see if other methods of determining the coefficient of friction for a sled sliding over a sports surface give values similar to those obtained using the friction sled method. A kinematic study would be useful to see whether the athlete's sprinting mechanics during a sled-towing exercise are the same on different types of sports surfaces.

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Tables

Table I. Coefficient of kinetic friction for a sled sliding over four sports surfaces (± 95% confidence interval).

Surface	Coefficient of friction (μ)
Rekortan athletics track	0.58 ± 0.01
Natural grass rugby pitch	0.45 ± 0.01
Artificial grass 3G football pitch	0.35 ± 0.01
Artificial grass hockey pitch	0.21 ± 0.01

Note: Source data are plotted in Figure 1.

Table II. Results from pairwise comparison tests of the influence of four sports surfaces on unloaded 30-m sprint time.

Comparison surfaces	Mean difference (s)	*p*	Cohen's *d*
Athletics - rugby	–0.05	0.15	0.1
Athletics - football	–0.37	0.02*	0.9
Athletics - hockey	–0.10	0.69	0.2
Rugby - football	–0.32	0.02*	0.8
Rugby - hockey	–0.05	0.99	0.1
Football - hockey	0.27	<0.001*	1.0

* $p < 0.05$

Table III. Results from pairwise comparison tests of the influence of four sports surfaces on the rate of increase in 30-m sprint time in a sled-towing exercise.

Comparison surfaces	Mean difference (s/BW)	*p*	Cohen's *d*
Athletics - rugby	–0.2	0.99	0.3
Athletics - football	0.3	0.71	0.5
Athletics - hockey	2.6	<0.001*	4.9
Rugby - football	0.5	0.24	0.8
Rugby - hockey	2.8	<0.001*	5.7
Football - hockey	2.3	0.005*	3.5

Note: BW, body weight.

* $p < 0.05$

Figures

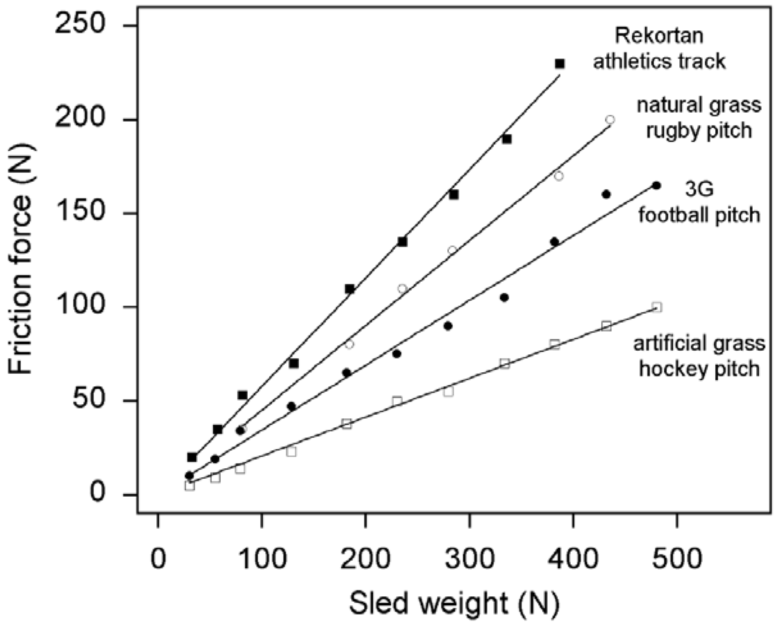

Figure 1. This plot shows the increase in friction force with increasing sled weight for four common sports surfaces. The gradient of the line of best fit gives the coefficient of friction (μ) for the surface (Table I). The selected sports surfaces show a wide range of coefficient of friction values (μ = 0.21–0.58).

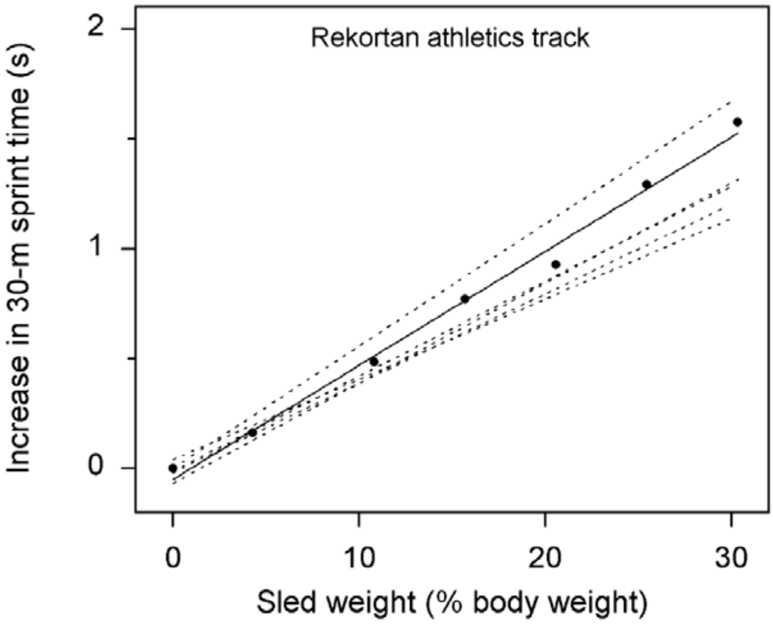

Figure 2. The 30-m sprint time when towing a weighted sled increased linearly with increasing sled weight. Lines are for six male rugby players towing a sled on a Rekortan athletics track, but data points are shown for one player only (thick line).

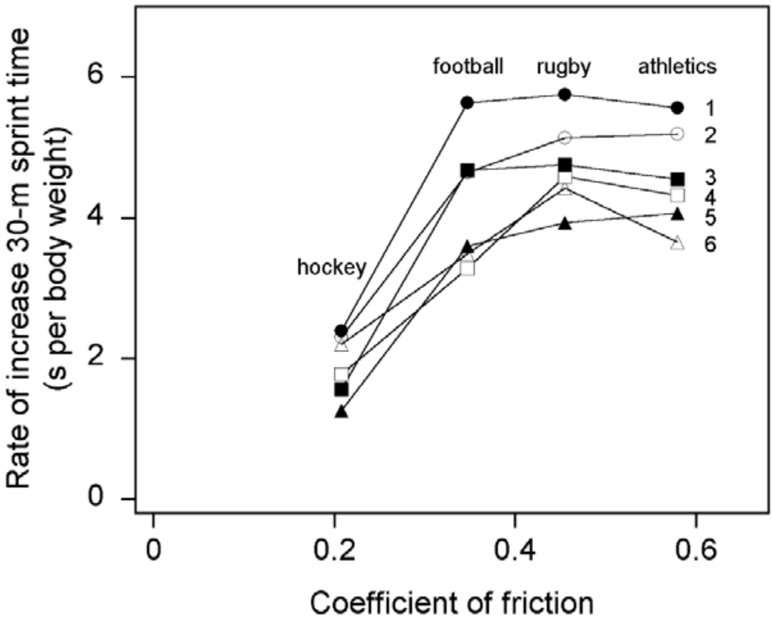

Figure 3. This plot shows the effect of the sports surface on the rate of increase in 30-m sprint time with increasing sled weight. Data for six male rugby players (Labels 1–6). The rate of increase in 30-m sprint time for the hockey pitch was substantially less than for the other surfaces, but there was no significant difference between the Rekortan athletics track, rugby pitch, and 3G football pitch. The rate of increase in 30-m sprint times on the sports surfaces did not show the expected steadily increasing trend as the coefficient of friction of the sports surface increased.