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Abstract:

Purpose: To compare critical speed measured from a single-visit field test of the distance-time relationship with the 'traditional' treadmill time to exhaustion multi-visit protocol. **Methods:** Ten male distance runners completed treadmill and field-tests in order to calculate critical speed (CS) and the maximum distance performed above CS (D′). The field-test involved 3 runs on a single visit to an outdoor athletics track over 3600 m, 2400 m and 1200 m. Two field-test protocols were evaluated using either a 30-min recovery or 60-min recovery between runs. The treadmill test involved runs to exhaustion at 100, 105 and 110% of velocity at $\dot{V}O_{2\ max}$, with 24-hours recovery between runs. **Results:** There was no difference in CS measured with the treadmill, 30-min and 60-min recovery field tests, ($P<0.05$). CS from the treadmill test was highly correlated with CS from the 30 and 60-min field tests ($r=0.89$; $r=0.82$, $P<0.05$). However there was a difference and no correlation in D′ between the treadmill test and the 30 and 60-min field tests ($r=0.13$; $r=0.33$, $P>0.05$). A typical error of the estimate of 0.14 $m \cdot s^{-1}$ (95% confidence limits: 0.09-0.26 $m \cdot s^{-1}$) was seen for CS and 88 m (95% confidence limits: 60-169 m) for D′. A coefficient of variation of 0.4% (95% confidence limits: 0.3-0.8%) was found for repeat tests of CS and 13% (95% confidence limits: 10-27%) for D′. **Conclusion:** The single-visit method provides a useful alternative for assessing CS in the field.

Keywords: Critical speed, endurance, laboratory-testing, treadmill running, track running.

Introduction:

A track based field test of the distance-time relationship with critical speed (CS) has been suggested as a useful method to assess endurance runners' fitness.[1] Kranenburg and Smith[1] conducted a direct comparison of CS determined on the treadmill and in the field. They found a strong correlation between CS for both tests (r = 0.94, P < 0.01). However athletes would need to make major adjustments to their training schedule in order to accommodate the protocol for this field test (a minimum of three track tests across two consecutive days). Therefore, whilst a CS field test's ecological validity may be appealing for athletes and coaches, the feasibility of the repeated days of testing prevents its wide-scale adoption.

We have recently developed a field test of CS where all measurements are taken on the same day in a single visit.[2] This new protocol could enable the measurement of CS to be more accessible and less time consuming for athletes and coaches to adopt. This may be important as for certain sports field tests may be preferable to laboratory tests.[3] Often field tests are viewed as less reliable than laboratory tests, due to the lower level of control over environmental variables. Field tests may provide greater ecological validity due to their greater specificity to a given sports performance.[3] For example a runner may see greater relevance for a test conducted on an athletics track rather than on the treadmill. Moreover, treadmill protocols tend to use time to exhaustion trials at a set speed[4-6] whereas field-based protocols can benefit from fixed distance trials that closely mimic the demands of competitive races. Whilst fixed distance self-paced trials are possible on a treadmill, they are complicated to conduct and tend to not allow flexible changes of pace typical of an athlete on a running track.

The aim of this study was to assess the validity and reliability of CS determined from a single-visit field test by comparing it with a traditional treadmill time to exhaustion protocol.

Methods:

Participants:

Ten male middle-distance runners (age: 39±7yrs; Stature: 181±7cm; Mass: 75±5kg, $\dot{V}O_{2\,max}$: 60.7±2.8mL·kg^{-1}·min^{-1} and 5km personal best time: 1136±61sec) were recruited for the study. All participants were competitive club standard runners who had been competing for a minimum of 2 years. All participants provided written informed consent for this study that had been approved by the University's ethics committee.

Study Design:

The protocol involved a total of 7 exercise testing sessions for each participant. Visit 1 included a maximal incremental treadmill test to determine $\dot{V}O_{2\,max}$, and a familiarization for the treadmill based CS test. During visit 2 participants were familiarized with the CS field test using a 30-min recovery between each of 3 runs. After these initial testing and familiarization visits, a further 3 'experimental' laboratory visits were undertaken to determine CS on the treadmill. These visits involved constant speed runs to exhaustion. Two further 'experimental' field-testing sessions took place. On each field testing visit participants completed 3 fixed distance timed runs, on one occasion with a 30-min recovery between runs and on a separate day with a 60-min recovery.

All testing sessions were completed in a random order and all tests were completed at the same time of day (±2hrs). Participants were instructed to arrive for testing in a rested and fully hydrated state, at least 3 hours post-prandial and having avoided strenuous exercise in the preceding 24 hours. Prior to each test session participants completed a standardized warm-up consisting of 5-min self-paced jogging, followed by 5-min of their usual stretching exercises.[7] All 7 testing sessions for each participant were completed within a period of 3-weeks.

Preliminary visit protocol:

Participants' body mass and stature was measured with a Beam Scale and Stadiometer (Seca, Birmingham, UK). Testing was conducted in two parts; the first part was a submaximal incremental treadmill test (Pulsar 3P; h/p/cosmos Sports and Medical, Nussdorf-Traunstein, Germany) using a treadmill gradient of 1%.[8] The initial treadmill belt speed was set at 12 $km \cdot h^{-1}$ and increased by 1.0 $km \cdot h^{-1}$ every 4-min. Participants completed a total of 3 stages throughout which expired gases were measured on a breath-by-breath basis (MetaLyzer; Cortex Biophysik GmbH, Leipzig, Germany). The gas analyzer was calibrated prior to use according to the manufacturer's guidelines, using a calibration gas of known composition and a 3-litre syringe (Hans Rudolph Inc. Kansas, USA). Running economy was calculated over the 3 submaximal velocities from the average $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) for the last min of each stage.[9] After completing the third 4-min stage participants continued straight into the second phase of testing. This involved 2-min stages with velocity increments of 1 $km \cdot h^{-1}$ until volitional exhaustion. Subsequently, $\dot{V}O_{2\,max}$ was calculated as the highest $\dot{V}O_2$ achieved during the test, using a rolling 1-min average. The velocity at $\dot{V}O_{2\,max}$ (v-$\dot{V}O_{2\,max}$) was calculated by solving the regression equation describing the relationship between $\dot{V}O_2$ at sub-maximal intensity and $\dot{V}O_{2\,max}$.[10]

After a 30-min recovery participants completed a familiarization trial of the treadmill based CS test protocol (detailed below). Environmental conditions during the preliminary visit session were within a temperature, pressure and relative humidity range of 18.0-19.5˚C, 745-756mmHg and 34-55%.

Treadmill CS test protocol:

Three constant speed time-to-exhaustion runs that followed the same protocol as previous treadmill CS tests[7] were conducted. The velocities for each participant were set at 100, 105 and 110% of their v-$\dot{V}O_{2\ max}$. Runs were conducted on separate days with a minimum of 24-hours recovery.[7,11] Runs were hand timed to the nearest second and the distance run was subsequently calculated. During the test elapsed time, distance covered and velocity were masked from the participant's view. The treadmill speed was checked prior to the study by timing belt revolutions. The treadmill speed was always within 0.02 $m{\cdot}s^{-1}$ of the desired speed. Throughout testing environmental conditions were within a temperature, pressure and relative humidity range of 18.2-19.6^{o}C, 749-761mmHg and 33-54%.

Field test protocol:

Each participant completed three runs on a standard outdoor 400-m athletics track. The 3 runs were over distances of 3600 m, 2400 m and 1200 m (9, 6 and 3 laps) and were conducted in this order for all sessions. These distances were chosen to result in completion times of approximately 12, 7 and 3 min.[11] Participants were instructed to complete each trial in the fastest time possible, and runs were hand-timed to the nearest second. Chidnok et al[12] recently reported that exhaustion during high-intensity exercise was unaffected when pacing strategy is self-selected. All three runs were conducted on the same day, once with a 30-min rest between each run and on a separate day with 60-min rest between runs. Participants were not provided with feedback on the elapsed time during the track runs. Testing was not conducted if wind speed > 2.0 $m{\cdot}s^{-1}$ was measured. Mean environmental conditions during the field tests were: temperature 11.5°C (range 8.6-13.4˚C), humidity 72% (range 56-83%.), barometric pressure 758mmHg (range 739-776mmHg) and wind speed 1.4 $m \cdot s^{-1}$ (range 0.2-1.8 $m \cdot s^{-1}$).

Statistical analysis:

Participants' CS and D′ were calculated from the treadmill and field test runs using a linear distance-time model. Data were checked for normality of distribution using the Shapiro-Wilk statistic. Repeated-measures ANOVA were used to identify differences in CS and D′ between the treadmill and field tests. The Pearson product moment correlation coefficient was used to assess the relationship between the treadmill and field tests. The 95% limits of agreement and Bland Altman plots[13] along with the typical error of the estimate were calculated to assess agreement between methods. The reliability of the distance-time relationship over repeated tests was assessed by comparing CS and D′ from the field familiarization trial and the 30-min field-test. The within-participant variation was expressed as a coefficient of variation (CV) derived from log-transformed data.[14] The 95% confidence intervals were calculated for each CV. The 95% limits of agreement were calculated to assess the variability of the repeated tests. Analysis was conducted using the SPSS statistical software package (IBM SPSS statistics, Rel. 20.0, 2011. SPSS Inc. Chicago, USA). Statistical significance was accepted at $P < 0.05$ for all tests.

Results:

The parameters calculated from the treadmill and field tests are shown in Table 1. There was no significant difference in CS ($m \cdot s^{-1}$) between the 3 tests (treadmill, 30-min field and 60-min field) (P=0.80). D′ (m) differed between the 3 tests ($F_{1.2, 11.0} = 25.1$, $P < 0.01$), being significantly higher in the treadmill test than in the 30 and 60-min field tests ($P < 0.01$).

The correlation between CS from the laboratory and field tests are shown in Table 2. A strong relationship was seen between treadmill CS and CS from the 30-min ($r = 0.89$, *P*<0.01) and 60-min (*r* = 0.82, *P*<0.01) field tests. Strong relationships were also evident between the CS (*r* = 0.96, *P*<0.01) and the D′ (*r* = 0.77, *P*=0.01) from the 30 and 60-min field tests. However, there was no significant relationship between the D′ from the treadmill test and D′ from the 30 (*r* = 0.13, *P* = 0.72) and 60-min (*r* = 0.33, *P* = 0.36) field tests.

The 95% limits of agreement method was used to assess the level of agreement between the CS from the treadmill test and the CS from the 30 and 60-min field tests. Results revealed a close agreement between methods (95% limits of agreement = 0.25 $m{\cdot}s^{-1}$ and 0.30 $m{\cdot}s^{-1}$ respectively). The D′ 95% limits of agreement between the treadmill test and the 30-min and 60-min field tests were 186.97 and 156.53 m respectively. The Bland-Altman plots for CS and D′ can be seen in Figure 1.

The typical error of the estimate was calculated by using the field test as the practical variable and the treadmill test as the criterion variable.[14] The typical error of the estimate for CS was 0.14 $m{\cdot}s^{-1}$ (95% confidence limits: 0.09-0.26 $m{\cdot}s^{-1}$) for the 30-min field test and 0.16 $m{\cdot}s^{-1}$ (95% confidence limits: 0.11-0.31 $m{\cdot}s^{-1}$) for the 60-min field-test. The typical error of the estimate for D′ was 88 m (95% confidence limits: 60-169 m) for the 30-min field test and 84 m (95% confidence limits: 57-161 m) for the 60-min field test.

The R^2 for the linear regression equations to determine CS and D' was greater than 0.999 for all three tests

The reliability of the distance-time relationship over repeat tests expressed as a coefficient of variation was 0.4% (95% confidence limits: 0.3-0.8%) for CS. However, D′ proved less reliable with a coefficient of variation of 13% (95% confidence limits: 10-27%). There was no difference in CS or D′ across the two trials (*P*=0.34 ; *P*=0.67). The 95% limits of agreement were ±0.05 $m{\cdot}s^{-1}$ of the measure for CS and ±20 m of the measure for D′.

Discussion:

The main finding of this study was that a single-visit CS field test was not different to that measured over several visits in the laboratory. Differences in D′ were evident between test methods (Table 1), with the exact reason for these differences remaining unclear. Although the assessment of D′ was less reliable than CS (CV 13.3% and 0.4% respectively), coefficient of variation values were similar to those previously reported during field and laboratory-based testing.[2,15]

There was no significant difference between CS on the track (4.07 $m \cdot s^{-1}$) compared to the treadmill (4.05 $m \cdot s^{-1}$). The typical error of the estimate for CS was 0.14 $m \cdot s^{-1}$ that Hopkins[14] suggests can be interpreted as small. The strong correlation between the CS from the field and treadmill tests ($r = 0.89$, $P < 0.01$) is similar to previous work[1] ($r = 0.94$, $P < 0.01$).

The D′ was higher with the treadmill protocol (249.7 m) compared to the 30-min (106.4 m) and 60-min (102.4 m) field protocols. The typical error of the estimate for D′ of 88 m is interpreted by Hopkins[14] as moderate. The CS and D' were measured with fixed distance runs in the field and time to exhaustion runs on a treadmill. Laursen et al[16] previously compared these approaches on a treadmill and reported lower levels of reliability for constant speed time-to-exhaustion tests compared with time-trial running tests. The differing reliability of these approaches may have influenced the variables computed from the treadmill and field tests. Additionally, due to the comparison of fixed distance and time to exhaustion runs, it was not possible to exactly match the performance time between comparable runs. During the 3 treadmill runs participants ran at percentages of their v-$\dot{V}O_{2max}$ estimated to produce an exhaustion time similar to that of the field runs. It has been suggested that CS and D′ are dependent on the range of exhaustion times (t_{lim}) achieved and that higher values of t_{lim} result in a higher calculated D′.[17] A longer t_{lim} during the treadmill runs might contribute to the higher D′ found. However this was not found to be the case as there was no difference (P = 0.87) between the combined t_{lim} for the 3 treadmill (556 ± 232) and 30-min field (566 ± 248) runs. Therefore, it is unlikely that differences in t_{lim} are responsible for the difference in D′ between the treadmill and field tests.

Figure 2 shows that participants covered any given distance at a faster speed on the treadmill than in the field. The reasons for this remain unclear but are unlikely to be related to accumulated fatigue as a consequence of the 30 or 60-min recovery time during the single-visit field test protocol. If fatigue were a factor, then the 3600 m run (i.e. the first distance run in the field protocol) would yield similar times (as fatigue should not be a factor). It can be seen from Table 3 that this is not apparent, as participants' mean speed over 3600 m is ~ 4% higher on the treadmill than in the field.

Furthermore, if residual fatigue were a factor it would be logical to expect the difference between laboratory and field tests to be smaller when the 60-min recovery was utilized. Again, it can be seen from Table 3 that this is not the case, and thus it would appear that the lower D′ in the field tests was not a consequence of residual fatigue during the single-visit field-test protocol.

The exact reason for the differences observed in D′ during this study remain unclear. However, inherent differences in the mechanics of indoor (treadmill) and outdoor (track) running might be responsible. Jones and Doust[8] suggest that a 1% treadmill gradient best replicates the demands of outdoor running for speeds between 2.9 and 5.0 $m \cdot s^{-1}$. The current findings suggest that a 1 percent gradient for treadmill running is less challenging than track running, and as a consequence, predicted time to cover a set distance on the treadmill was quicker than in the field (Table 3). The difference was greater for 2400 m and 1200 m distances where the mean speed approached and then exceeded 5.0 $m \cdot s^{-1}$. It seems possible that a treadmill grade of greater than 1% may be necessary for the speeds used in the current study. These changes to the treadmill protocol may then bring the treadmill D′ measurement more in line with that of the field protocol. However, it is unlikely that the fairly large differences between treadmill and field running reported in Table 3 can be solely attributed to treadmill grade. Furthermore it could be argued that differences between indoor and outdoor running would presumably effect the CS as well as the D′. However it has been suggested that the y-intercept is more sensitive to variations in time than the slope,[17] justifying how differences between indoor and outdoor running may effect D′ whilst the CS remains unchanged.

30 or 60-min recovery?

There was no significant difference in CS calculated from the 30-min or the 60-min field tests (Table 1). This is in keeping with previous research which reported no significant difference compared to a control value, following either a 2, 6 or 15-min recovery.[18] There was also no significant difference in D′ between the 30 and 60-min field tests (Table 2). In contrast to the current study, the longest recovery duration in previous research was 15-min[18] by which point 86% repletion was reported. Consequently, a recovery of longer than 30-min between runs seems unnecessary for the calculation of CS and D′ during a single-visit field test. When using the 30-min rest protocol the field test can be accommodated into a single session of around 90-min duration.

Reliability:

The results of the current study demonstrate that CS can be reliably tested using the 30-min field-test. The CV of 0.4% between repeat runs is lower than previously reported (1.7%) using the single visit field test[2] and also lower than the value reported (1.8%) for treadmill based CS reliability.[15] It is important to note that participants in the current study were experienced in the use of the single-visit protocol before starting this study. This greater level of experience may explain the lower coefficient of variation for CS found in the current study.

In agreement with previous literature[2,15] D′ proved to be less reliable than CS, with a coefficient of variation of 13.3%. Whilst the increased level of familiarization seemed to improve the reliability of CS, the same was not true for D′ where the coefficient of variation was similar to the previously reported values of ~14%[2,15]. The lower reliability of D′ could be explained by the fact relatively small changes in performance time during the shortest trial in the distance-time relationship have been suggested to result in large changes in the resulting D′.[19] This is supported by the reliability of the actual performance times of the three individual runs in the familiarization and 30-min field test trials. The mean group typical error expressed as a coefficient of variation became progressively higher as the trial length decreased (0.6%, 0.8% & 1.0% for the 9-lap, 6-lap and 3-lap runs respectively). This is further supported by the suggestion that the y-intercept (seen here as D′) is more sensitive to variations in time than the slope (CS).[17]

Direct comparisons of the reliability of CS and D′ with CP and W′ are sparse. When previous studies performed on cycle ergometers were reviewed[15,20] aerobic power was more variable

(2.3-7.6%) and anaerobic capacity was slightly less variable (8.4-14%) then the findings of the current study and previous reports for running exercise[2,15].

Practical Applications:

This study has found good agreement in CS between a traditional multi-visit treadmill test and a new single-visit field based test. This new protocol is more accessible and less time disruptive of training for athletes, therefore allowing coaches to monitor and model athletic performance more easily.

Conclusions:

The single-visit field test of CS using a 30-min rest period agrees well with CS determined over multiple visits using a treadmill. Therefore, when assessing CS the single visit field test protocol may provide a suitable alternative to treadmill based testing over multiple days.

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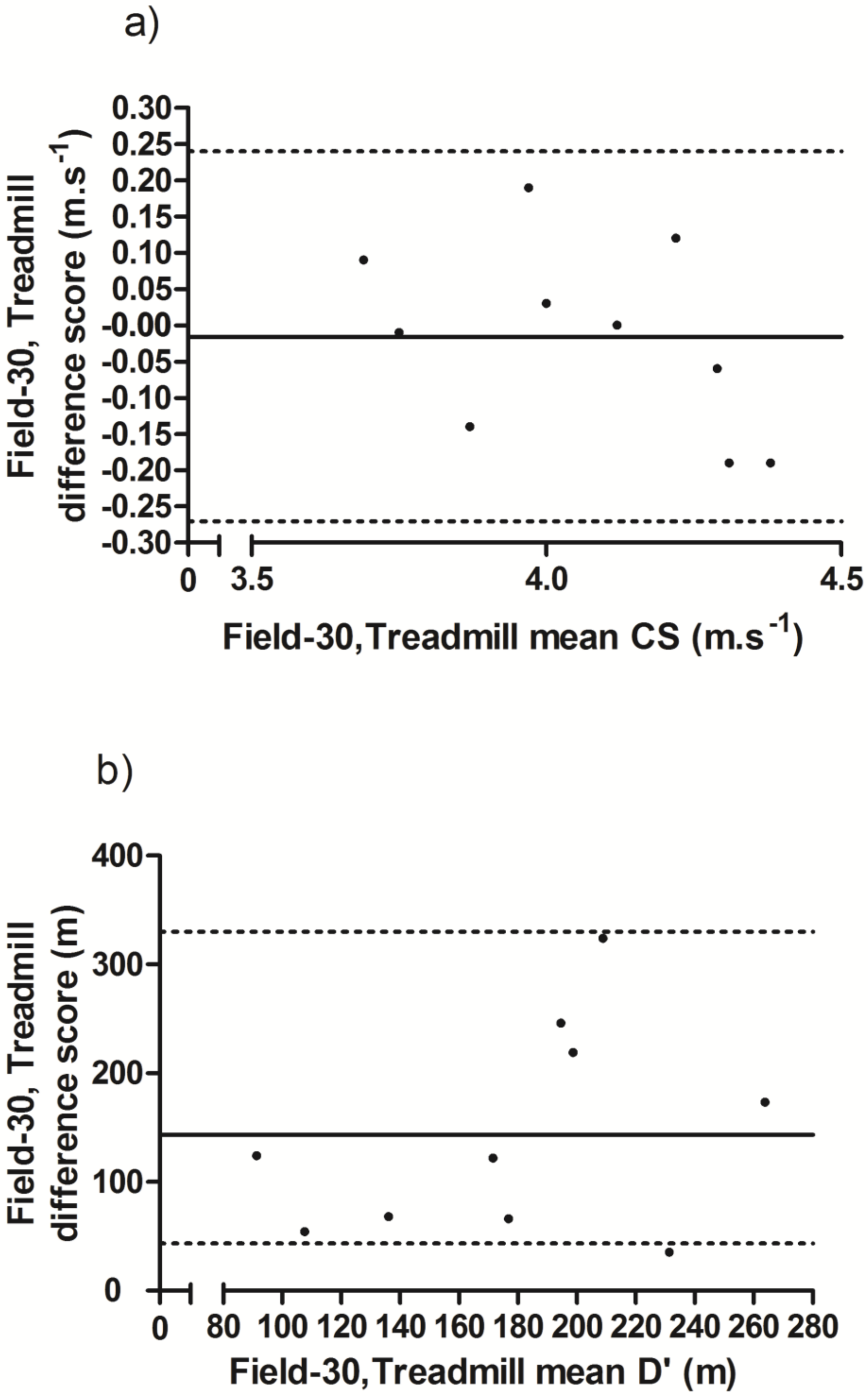

Figure 1: Bland-Altman plot of differences in CS (a) and D′ (b) between the treadmill and the 30-min field tests. The solid horizontal lines represent mean bias, whilst the dashed lines represent the 95% limits of agreement.

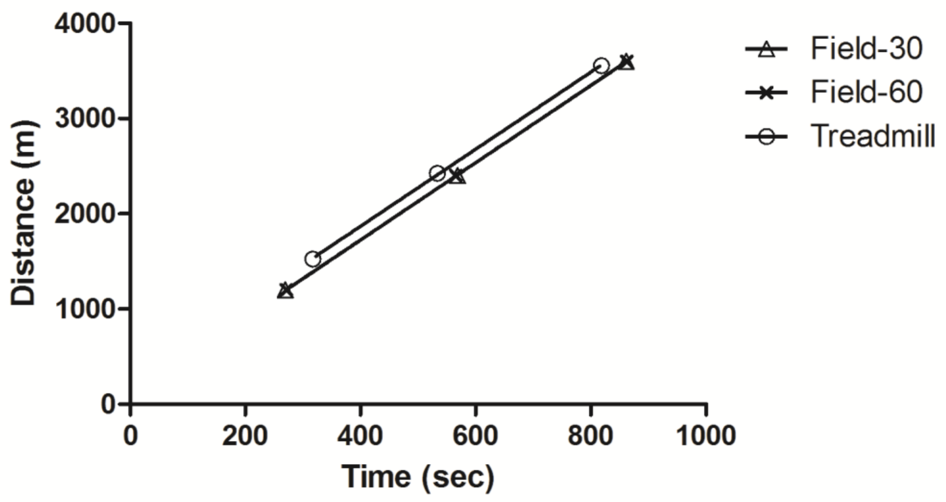

Figure 2: The distance-time relationship for the three test methods. Data are calculated from the mean distance and time (n=10) for each test method.

Table 1: Participants' CS and D′ from the treadmill and field tests.

	CS ($m \cdot s^{-1}$)			D′ (m)		
	Field-30	**Field-60**	**Treadmill**	**Field-30**	**Field-60**	**Treadmill**
1	4.47	4.42	4.28	47	78	371
2	4.31	4.31	4.26	102	65	170
3	4.16	4.14	4.28	29	61	153
4	3.99	4.04	4.01	110	113	233
5	3.94	4.04	3.80	144	135	210
6	3.87	3.82	4.06	177	149	351
7	3.64	3.79	3.73	214	138	249
8	3.76	3.65	3.74	89	140	308
9	4.40	4.42	4.21	80	83	135
10	4.12	4.12	4.12	71	62	317
X	4.07	4.07	4.05	106*	102*	250
σ	0.28	0.26	0.22	57	36	84

Field-30 = 30-min recovery between runs ; Field-60 = 60-min recovery between runs. * Significantly different to Treadmill, $P < 0.01$

Table 2: Correlation between treadmill and field tests.

	CS Treadmill	**CS Field-30**
CS Field-30	0.89*	
CS Field-60	0.82*	0.96*

Field-30 = 30-min recovery between runs ; Field-60 = 60-min recovery between runs. * $P < 0.01$

Table 3: Predicted mean speed ($m \cdot s^{-1}$) over three set distances.

	Mean Speed ($m \cdot s^{-1}$)			
Distance (m)	**Treadmill**	**Field-30**	**Field-60**	**Difference (%)**
3600	4.35	4.18	4.18	4.2
2400	4.52	4.24	4.24	6.7
1200	5.12	4.44	4.44	15.2

Data are calculated from the linear distance-time relationships in Figure 2. Field-30 = 30-min recovery between runs; Field-60 = 60-min recovery between runs.