ENVIRONMENTAL AND VENUE-RELATED FACTORS AFFECTING PERFORMANCE OF ELITE MALE TRACK ATHLETES

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Abstract

Effects of environmental and other venue-related factors need to be taken into account when tracking an individual athlete's competitive performance. We report the effects of such factors on performances of elite male track athletes. Performance times throughout the athletic careers of male track athletes who placed in the top 16 of their event in at least one Olympic Games or World Championship between 2000 and 2009 were downloaded from the athletics results database at tilastopaja.org. In the 10 running events (100-m through 10000-m, including hurdles and steeplechase) there were 619 athletes with 43999 performances, all with environmental and venue-related information. Times for a given event were log-transformed to estimate percent effects in a mixed linear model with fixed effects for the environmental and venue-related factors and random effects for within-athlete race-to-race variability and individual athlete performance progression. After adjustment for quadratic trends for year of competition and each athlete's age, the model provided estimates of effects of level of competition (Olympics and World Championships vs other competitions), altitude (sea level vs ≥1000 m), timing method (electronic vs stopwatch), wind speed (linear numeric), and venue (outdoors vs indoors). Uncertainty in estimates of environmental effects expressed as 99% confidence limits was sufficiently small (at most ±0.9%) for almost all outcomes to be clear when interpreted in relation to smallest important changes (0.3–0.5%). Olympics and World Championships produced substantially faster times for events up to 400-m (0.7–0.8%) but slower times for the 1500-, 5000- and 10000-m events (0.6%, 1.2%, and 0.2%), presumably reflecting differences in preparation or pacing. Altitude produced substantially faster times in some 100-, 200- and 400-m and hurdle events (0.1–0.5%) but substantially slower times in longer races (1.1–2.4%), reflecting opposing effects of altitude on air resistance and aerobic power. Stopwatch times were faster for sprints (0.3–0.5%) but slower for 1500-m and longer events (0.6–2.1%), possibly because of bias in reaction time and confounding by level of competition. A typical trailing wind of 2 m·s⁻¹ had small benefits (0.5–0.8%) on the three sprint events where wind-speed was recorded. Indoor events were consistently slower (1.6–2.3%), a likely consequence of tight bends. In conclusion, use of these environmental and venue-related effects to adjust performances of male track athletes will make comparative assessment of all their performances more meaningful.

Introduction

Various environmental and venue-related factors affect performance outcomes in track running events. When considering an athlete’s performance for purposes of development of talent, advising athletes about specialty events, or selection of teams for competitions, it would be helpful to quantify the effects of these factors, thereby enabling the athlete and other interested parties to adjust the performance to meaningfully compare it to their previous performances and to those of their peers.
Previous research into such effects is limited to the two most recognisable environmental factors that impact on sprint performance: wind speed and altitude. A number of studies have attempted to estimate the effects of wind on the sprint events (Garcia & Garcia, 1971; Heidenstrom, 1980, 1982; Hill, 1928; Linthorne, 1994; Mureika, 2003; Ward-Smith, 1984, 1985) and on hurdles (Spiegel & Mureika, 2003; Ward-Smith, 1997). These researchers each recommended different time adjustments. Studies of the effects of altitude on running events have focussed on sprints and hurdles (Dapena & Feltner, 1987; Lloyd, 1967; Heidenstrom, 1993; Quinn, 2003), but there has been no research on middle- and long-distance events.

We adopted an empirical approach to estimating the effects of wind speed, altitude and other venue-related factors on actual performance times in competitions. We used athletes’ actual performances together with associated data to quantify the effect of these factors. There is now a comprehensive Web-based database, tilastopaja.org., of athletics performances that offers the possibility to acquire performance data of athletes competing as individuals in national and international events. This recent resource enables access to athletes’ biographical information, results of athletes’ performances, and environmental and venue-related conditions under which the athletes competed. Factors other than wind-speed and altitude also affect performance in track running events. Our study identified additional environmental factors as well as some venue-related factors: level of competition, timing method, and indoor vs outdoor venue. Conventional repeated-measures analysis of variance cannot cope with the irregular complex structure of these data, but mixed linear modeling can. Using this technique, we have estimated the effect of the five environmental and venue-related factors on ten men’s track running events.

Method

All competition performances published at tilastopaja.org for male track athletes who finished in the top 16 of their event at an Olympic Games or a World Athletics Championships between 2000 and 2009 were used for the analysis. The events were 100-m (6628 performances for 56 athletes), 110-m hurdles (6971 performances for 56 athletes), 200-m (4651 performances for 59 athletes), 400-m (6062 performances for 70 athletes), 400-m hurdles (5441 performances for 62 athletes), 800-m (4961 performance for 56 athletes), 1500-m (3967 performances for 64 athletes), 3000-m steeplechase (2642 performances for 58 athletes), 5000-m (1719 performances for 70 athletes) and 10000-m (957 performances for 68 athletes). The period that the athletes were in the database ranged from 6.5 ± 3.4 y (mean ± SD) (10000-m) to 10.4 ± 3.5 y (110-m hurdles). In all events, the age of athletes at the midpoint of their period in the dataset was ~ 24 ± 4 y.

Most of the environmental and venue-specific data were captured exactly as recorded at the tilastopaja site: venue above or below 1000 m; outdoor or indoor track; level of competition (global, i.e., Olympic Games, World Athletics Championships and the World
Junior Athletics Championships or other, i.e., grand prix and other international and national competitions); fully automated or hand timing; and wind-speed in m s\(^{-1}\), with a negative value for a head wind. We excluded performances achieved on an indoor oversized track (i.e., circumference greater than 200 m). The few sprint and hurdle performances where wind-speed was not recorded were discarded. Where athletes were subsequently disqualified from the competition (for whatever reason), the performance was also discarded.

Performance times were log-transformed to estimate percent effects of the stated environmental effects using the mixed linear model procedure (Proc Mixed) in the Statistical Analysis System (Version 9.2, SAS Institute, Cary, NC). Environmental and venue-specific variables were included in the model as fixed main effects. For windspeed we estimated the same linear effect for head and tail wind (with a change of sign), having used Pugh’s (1970) model for the effects for wind resistance on running to demonstrate that a 2 m s\(^{-1}\) head and tail wind produced similar changes in 100-m sprint speed, (-6.0% and 5.4% respectively). For some events we investigated interactions between some of these variables, but differences between the levels of the interactions were generally trivial and are not presented here. Random effects were included to allow for each athlete to have a unique quadratic trend for the effect of age on performance. Adjustments from quadratic trends were made for the year of competition and for each athlete’s age. The residual random effect in the model represented within athlete competition-to-competition; a different residual variance was specified for the following levels of competition: World Championships and Olympic Games, World Junior Championships, and other competitions.

The effects were interpreted via uncertainty (99% confidence limits) with respect to a scale of magnitudes of effects on performance. The thresholds for small, moderate, large and very large effects on performance were assumed to be 0.3, 0.9, 1.6 and 2.5 of the race-to-race within-athlete variability in competitive performance of elite athletes, (Hopkins, Batterham, Marshall & Hanin, 2009).

**Results**

Within-athlete performance variability ranged from a coefficient of variation of 1.3% through 2.2%, with generally greater variability in longer events (1.6% to 2.1%). There was little difference in within athlete variability between the three levels of competition. Uncertainty in estimates of environmental effects expressed as 99% confidence limits was sufficiently small (range ±0.03% through ±0.9%) for almost all outcomes to be clear when interpreted in relation to smallest important changes (0.3 of the within-athlete variability). The effects (%) of the five environmental factors on the ten track events are shown in Table 1.
Table 1: Effect (%) and 99% confidence limits of venue and environmental factors on time in men’s running events.

<table>
<thead>
<tr>
<th>Event</th>
<th>Global Competitions vs Other Competitions</th>
<th>Altitude: ≥1000 m vs &lt;1000 m</th>
<th>Stop-watch Timing vs Fully Electronic Timing</th>
<th>Following wind of 2.0 m·s⁻¹</th>
<th>Indoor vs Outdoor venue</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-m</td>
<td>-0.8; ±0.2</td>
<td>-0.5; ±0.2</td>
<td>-0.5; ±0.5</td>
<td>-0.8; ±0.1</td>
<td>-</td>
</tr>
<tr>
<td>110-m hurdles</td>
<td>-0.7; ±0.2</td>
<td>-0.1; ±0.3</td>
<td>-0.3; ±0.6</td>
<td>-0.5; ±0.1</td>
<td>-</td>
</tr>
<tr>
<td>200-m</td>
<td>-0.7; ±0.2</td>
<td>-0.4; ±0.3</td>
<td>-0.4; ±0.8</td>
<td>-0.5; ±0.1</td>
<td>1.7; ±0.2</td>
</tr>
<tr>
<td>400-m</td>
<td>-0.7; ±0.1</td>
<td>-0.3; ±0.3</td>
<td>0.0; ±0.4</td>
<td>-</td>
<td>2.3; ±0.1</td>
</tr>
<tr>
<td>400-m hurdles</td>
<td>-0.8; ±0.2</td>
<td>-0.1; ±0.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>800-m</td>
<td>0.0; ±0.1</td>
<td>0.4; ±0.2</td>
<td>0.6; ±0.3</td>
<td>-</td>
<td>1.8; ±0.2</td>
</tr>
<tr>
<td>1500-m</td>
<td>0.6; ±0.2</td>
<td>1.9; ±0.6</td>
<td>0.7; ±0.6</td>
<td>-</td>
<td>1.6; ±0.2</td>
</tr>
<tr>
<td>3000-m steeplechase</td>
<td>-0.1; ±0.2</td>
<td>1.7; ±0.6</td>
<td>1.0; ±0.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5000-m</td>
<td>1.2; ±0.3</td>
<td>2.4; ±0.7</td>
<td>0.6; ±0.7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10000-m</td>
<td>0.2; ±0.4</td>
<td>1.1; ±0.9</td>
<td>2.1; ±0.9</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

In the estimate of the effect, a negative value indicates improvement (i.e., a faster time).

Performances at global competitions resulted in small improvements in times for events up to 400-m including 400-m hurdles (all 0.7% to 0.8%) but small to moderately slower times for the 1500-, 5000- and 10000-m events (0.6%, 1.2%, and 0.2%). The 800-m and 3000-m steeplechase showed trivial differences in times at global competitions when compared to other competitions. Performances at altitude showed trivial to small improvements in times in all sprint events including the two hurdles events, but moderate to large slower times (1.1 to 2.4%) in races longer than 800-m. Performances timed with a stopwatch showed trivial to small improvements in times for sprints up to 400-m (0.0 to 0.5%), but small to very large slower times for the longer events (0.6 to 2.1%). A typical trailing wind of 2 m·s⁻¹ had small benefits (~0.5 to 0.8%) on the three sprint events (100-m, 200-m, and 110-m hurdles). Performances at indoor competitions, in the four events that were contested both indoors and outdoors, showed large (1.6 to 2.3%) increases in times (slower times).

Discussion

Within-athlete variability

The within-athlete variability represents the residual error in the statistical model providing a means of assessing the models goodness of fit and therefore whether the estimates of the effects are trustworthy. This variability is the variation in competitive
performance that is still unexplained after the athletes’ trends in performance have been explained with quadratic trajectories that can only approximate the true trends, and after the environmental and venue-related effects have been accounted for by variables that can only approximate the true effects. An analysis of competitive performance of track athletes that is not based on such approximations is that of Hopkins (2005), who analysed performances from 17 competitions over a single international season of 101 days. He included mean time of each race as an effect, which automatically adjusted for all environmental and venue-related effects. Given the variability he observed (1.0% to 1.4%) was not much less than in our study (1.3% to 2.2%), indicates that our statistical model appears to be adequate for estimating environmental and venue-related effects.

**Competition level**

At global competitions, athletes in events up to and including the 400-m, tend to run as fast as they can in order to obtain their fastest time and to secure a high finishing position. In the middle- and long-distance events (1500-m through 10000-m), the aim of the athlete is to win the event, hence a tactical race rather than “running for a time” encounter ensues. By comparison, in other competitions (mainly Grand Prix) financial incentives are given for running a fast time and one or more pacemakers are engaged to ensure a fast race. Each athlete therefore approaches the varied-level competitions and the event they compete in with different outcome goals in mind and adopts an appropriate strategy to achieve their goal.

Our analysis showed that generally athletes in the three sprint events and the two hurdle events run faster times when competing at a global competition compared to other competitions. Interestingly, the magnitude of the effect was similar for each of these five events. The faster times in the sprint events at global competitions can be explained by way of winning these prestigious titles requires maximum effort, preceded by a tapering phase. Our results confirm that generally the middle- and long-distance events are run with a slower time at global competitions than at other competitions, probably due to tactical considerations. The 800-m times in global competitions have comparable times to those of other competitions due to the fact that the event is an “in-between event” – neither a sprint - an all-out effort, or a long distance race – a tactical encounter.

**Altitude**

The IAAF and athletics statisticians determined that performances achieved at venues ≥1000 m above sea level are designated as an “altitude performance”. Records can be set at altitude but are recorded as “achieved at altitude”. The setting of 1000 m as the decisive level is unclear and appears to be an arbitrary figure. A number of researchers have studied the effects of altitude and wind-speed on the 100-m (Dapena & Feltner, 1987), on the 200-m (Quinn, 2003) and on the 110-m hurdles (Spiegel & Mureika, 2003), whilst Heidenstrom (1993) debated the merits or otherwise of combining the effects of wind-speed and altitude
together and expressing them as an “equivalent wind” referred to sea level. His argument in favour of this method is based on the premise that altitude in the sprint events has the same effect as a tail wind, in lowering the pressure of air against a moving runner. He stated “It is fairer and more scientific, letting us do justice at all altitudes instead of blindly sticking a pin into a list of numbers or picking 1000 m as though there was something magical about it”. He produced a table showing the altitude ranges within which each nominal wind reading remains allowable – that is, becomes no greater than +2.0 m·s⁻¹ when converted to an equivalent wind. Our results would not support Heidenstrom’s suggestion, particularly in the 100-m and 110-m hurdles events, where the effect of altitude and of a following wind of 2.0 m·s⁻¹ were very different (100-m, -0.5; ±0.2% for altitude and -0.8; ±0.2% for assisting wind. 110-m hurdles, -0.1; ±0.3% for altitude and -0.5; ±0.1% for assisting wind). Only in the 200-m was the effect of altitude (-0.4; ±0.3%) and of a following wind (-0.5; ± 0.1%) similar.

Using the 1000 m altitude criteria to estimate the effect on performance in men’s running events, we found all five of the sprint events, including the two hurdles events, produced faster times when run at altitude. The two hurdles events produced only trivially faster times at altitude. Faster times at altitude of the five sprint events may be due to the lower air resistance at altitude. The 1500-m and 5000-m, and to a lesser extent the 3000-m steeplechase and the 10000-m each produced slower times at altitude. Slower times at altitude in middle- and long-distance events may be attributed to the reduction in the available oxygen at altitude and consequently the reduced aerobic power of the athlete. The 800-m, which produced small magnitude slower times, is regarded as a “break-even” event when run at altitude; the result of the reduced oxygen content of the air at altitude impacting more on the athlete’s performance than the advantage gained by the reduced air resistance. The results for all running events show that the disadvantageous effect that altitude has on the middle- and long-distance events in producing slower times is much greater than the beneficial effects gained in the sprints and hurdles events.

**Timing method**

Nowadays, hand-held stopwatches are infrequently used to record the elapsed time of a race. Notwithstanding, there are a few competitions where manual times are recorded (our dataset of 43999 performances contained 1100 (2.5%) hand-timed performances); primarily at low-key competitions at remote venues or as a back-up to a failed fully automated timing (FAT) apparatus. The scientific study of the variability and accuracy to be expected amongst track timekeepers using stopwatches is limited. No recent documentation of the difference to be expected between handheld watches and electronic timing in track athletics has been presented. There is a substantial amount of unpredictable random error in manual timekeeping, mainly due to inexperienced timekeepers, watch calibration errors, rounding to 1/10th of a second and the taking of the median time of the available watches (or the slower of the times if just two watches are used) as the recorded
time (IAAF, 2009). The current convention, used by athletics statisticians world-wide, based on calibration tests in the 1960’s, is to add 0.24 s to an athlete’s stopwatch time in events up to 400 m and to add 0.14 s to an athlete’s stopwatch time in events over 400 m to give a “corrected time”. Our results showed, as expected, that sprint event times are faster when manually timed rather than when FAT is used. Most of the difference can be attributed to timekeepers’ anticipating the finish, i.e. stopping their watch when they think an athlete would cross the line, rather than waiting to react to seeing the athlete cross the finish line. Our analysis showed a difference of 0.00 – 0.21 s between times taken manually and those taken using FAT for the 100-m, 200-m and 110-m hurdles. The differences fell well within the conventional 0.24 s used to “correct” for these events. The accepted value therefore probably underestimates the true ability of the timekeepers to accurately record both the start and finish of the race. In the 400-m the difference between manually taken times and FAT was 0.00 – 0.19 s. This is similar to the convention where 0.14 s is used when “adjusting” manually taken times to FAT in events of 400-m and above. Middle- and long-distance events (1500m upwards) had small to large time differences that were slower and well outside the convention of 0.14 s of those timed using FAT which is hard to explain but may be due to confounding factors. The lesser quality of athletes competing in events where hand timing is used, and likely slower running times at the lower quality competitions where hand timing was used, are possible explanations.

Wind speed

Measuring the wind speed in the 100-m, 200-m and 110-m hurdles has been arguably the most controversial topic in the sport since 1936 when it was first introduced (introduced in 1950 for the 200-m). Athletics statisticians and some officials have passionately debated the topic ever since and are of the collective view that wind measurements in these events are neither valid nor reliable (Heidenstrom, 1991; Murrie, 1985; Vanuytven, 1994; von Dreusche, 1994; Wilson, 2009). The origin of the setting of the +2.0 m·s⁻¹ wind speed limit for record purposes is clouded, but “was probably an arbitrary decision made by (name withheld) in 1936.” (Wilson, 2009). What scientific basis that figure had is uncertain. The value has not changed since and appears not to have been challenged.

Notwithstanding the debate as to the accuracy and validity of measuring the wind speed, a number of researchers have attempted to measure the effect of wind in sprint events. Data from Heidenstrom’s (1982) “rule of thumb” for the 100-m is 0.1 m·s⁻¹ of wind has an effect of 0.01 s. Hoffman (1994) showed that a +2.0 m·s⁻¹ wind had an advantageous effect of 0.16 s and a +4.0 m·s⁻¹ wind had an advantageous effect of 0.29 s on 100-m time. Tables to calculate for the wind effect on the 110-m hurdles are not specific, as a number of researchers, Ward – Smith (1985), and Linthorne (1994) argued that the wind effect should be similar to that in the 100-m event; about 0.10 s for a +2.0 m·s⁻¹ wind. Ward-Smith in his original calculations predicted that a +2.0 m·s⁻¹ wind reduces a 110-m hurdle race time by 0.24 s. Ward-Smith (1997), later revised his prediction to 0.13 s. Spiegel and Mureika
(2003) estimated the effect of a +2.0 m·s\(^{-1}\) wind on the 110-m hurdles is a faster time by 0.19s.

Using actual competition data we calculated that a following wind of +2.0 m·s\(^{-1}\) would have a 0.07 to 0.09 s advantage to a runner in the 100-m. Our analysis showed that the advantageous wind effect of a +2.0 m·s\(^{-1}\) wind in the 100-m was approximately half of that calculated by Hoffman, two to three times less than that suggested by Heidenstrom, and approximately and one-tenth of that calculated by Pugh’s model. Pugh’s estimate, based on measurement of energy consumption into a head wind is probably closest to the true effect. For the 110-m hurdles, we calculated the effect of a +2.0 m·s\(^{-1}\) wind to be advantageous by 0.06 to 0.08 s. This was much less than the 0.24 s Ward-Smith predicted in his early wind effects model for the event. His revised model (Ward-Smith, 1999), by adapting a recalculated 100-m wind effect model to the 110-m hurdles, resulted in a prediction of an advantage of 0.13 s for the 110-m hurdles, which is still greater than our calculated effect. Our wind-effect calculation was also much smaller than that predicted by Spiegel and Mureika’s (2003) model where the effect of a +2.0 m·s\(^{-1}\) wind in the 110-m hurdles was 0.19 s. Comparing the 100-m race with the 110-m hurdles race, the 100-m race is run at a faster speed, which will increase the effect of wind on the race time, but the 100-m runner runs for a shorter time, which will reduce the effect of wind. Linthorne (1994) argued that these two effects will come close to cancelling each other, and therefore the predicted effect of a +2.0 m·s\(^{-1}\) wind in the 110-m hurdles would be almost the same as in the 100-m. Our data showed that the wind effect on the 100-m is greater than that on the 110-m hurdles.

Our estimate showed different magnitudes of effect from those calculated by other researchers, a likely consequence of the different analytical approaches taken confounded by the inherent error of measuring wind-speed.

**Type of venue**

Each of the four running events (200-m, 400-m, 800-m and 1500-m) that are contested both indoors and outdoors produced slower times when held indoors. The reason can be attributed to two factors. First, indoor tracks are typically of a lap of 200 m – compared to 400 m for a standard outdoor track. As a consequence, indoor tracks have very tight bends. The runner competing indoors has to negotiate twice as many laps and consequently twice as many bends as they do for the same distance outdoors, making it difficult to maintain rhythm, balance and stride length on the tight bends. Secondly, given the only permanent indoor tracks in the world are all in the northern hemisphere, all indoor competitions are normally held between December and March – the winter months in the northern hemisphere. Normally an athlete would, at that time, be going through a training programme in preparation for the northern hemisphere summer outdoor season which runs from April/May until September. The athlete would therefore not be fully conditioned to peak at the time of the indoor season.
Conclusion

Using authentic performance and associated environmental and venue-related data from a single database and by utilising a mixed linear model for the analysis, we have demonstrated that certain environmental and venue related factors can have a substantial effect on performance outcomes. Intra-athlete performances can be adjusted using our calculations to take account of these effects, thereby enabling intra- and inter-athlete performances to be compared more meaningfully.

We recommend that further work be undertaken to establish if the arbitrary values of +2.0 m·s⁻¹ for wind speed for record purposes and ≥1000 m for altitude performances are the appropriate values to use. Further, we recommend that work be undertaken to overcome the inherent unreliability and invalidity issues of the way that the wind speed is measured.

Postscript

At the IAAF Congress held in Berlin in August 2009, three rule changes were made (IAAF, 2009) that may reduce the magnitude of the effect of wind-speed and hand held timing on performances. A wind-related amendment provides that in wind-affected events, the wind must be measured by an ultrasonic anemometer. Mechanical anemometers will no longer be acceptable (Rule 163.11). The rule change will enable a more accurate calculation of the wind-speed, but it still does not address the issue of wind-speed in the 200-m event or the variation in wind-speed across the width of the running track. Another rule change may be of only theoretical significance, given the prevalence of automatic timing in major events today. The IAAF increased the threshold for requiring automatic timing for record recognition from 400-m to 800-m. Hand timed 800-m marks will no longer be ratified (Rule 260.22(b)). Finally, there was the removal of the reference to stopwatches from the rule governing hand timing. Timers must now use only manually operated electronic timers with digital readouts. Analogue watches with sweep-second hands are no longer recognised (Rule 165.5).

References


