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18:4; 47-56, 2003

Energy system contribution in track running

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ABSTRACT

As a wide range of values have been suggested for the relative energetics of track running events, this collection of studies aimed to quantify the respective aerobic and anaerobic energy system contribution during actual track running. Subjects performed (on separate days) a laboratory graded exercise test and multiple race time trials. The relative energy system contribution was calculated based upon measures of race VO_2 *and accumulated oxygen deficit. Aerobic - anaerobic energy system contributions for male track athletes were 3000m; 86% – 14%, 1500m; 77% – 23%, 800m; 60% – 40%, 400m; 41% – 59%, 200m; 28% – 72% and 100m; 20% – 80%. This data, collected during specific track running events, compares well with previous estimates of relative energy system contributions. Additionally, the relative importance and speed of interaction of the respective metabolic pathways has implications to training for these events.*

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Introduction

This paper serves to review a series of studies re-investigating the relative energy system contribution to track running events between 100m and 3000m. The relative contribution and interaction of the respective energy systems for the provision of Adenosine tri-phosphate (ATP) during track running is of importance in order to understand the metabolic demands of an athletic event. This knowledge is useful for aiding the correct implementation of training programmes designed to optimise the metabolic production of ATP and hence achieve peak performance.

Knowledge of energy system contribution and interaction particularly applies to events that fall within exercise durations relying heavily upon both anaerobic and aerobic metabolism. Despite near maximal or maximal utilisation of anaerobic glycolytic and phosphorylative pathways, the provision of considerable aerobic energy is also required to perform these sustained high intensity efforts. Events such as 400m, 800m and to a lesser extent 1500m track races, lasting from approximately 45 sec to 5 min (depending on ability), fall within the category of demanding heavy reliance on all three energy pathways. Furthermore, while previous research (1) may have described little involvement of aerobic metabolism in events of short durations (up to 400m), recent data has shown that the speed of the interaction of oxidative processes to the overall metabolic supply is faster than previously described (2). Hence, an understanding of the energetics of these athletic events, particularly from actual track running data, is important for evaluating the contribution of the respective energy systems involved.

Two factors have hindered the previous quantification of the relative energy system contribution to track running events. Firstly, the use of outdated methods for the measurement of anaerobic metabolism and secondly, the lack of specific data measured during track running. While early research (3) reported energy system interaction to exercise of varying durations, methods used to quantify the anaerobic energy system contribution, including O_2 debt and blood lactate ($[La^-]_b$) methods, have since been shown to be inaccurate, hence casting doubt on the reported values (see Gastin (2) for a review). Recent research has utilised the more popular (although not universally accepted) accumulated oxygen deficit (AOD) method to measure anaerobic metabolism (4), which accordingly has been applied to the measurement of energy system contribution in track running (5). However, much of the recent literature reporting the energetics of track running has measured oxygen consumption (VO_2) during constant-velocity treadmill running, attempting to simulate the duration of the respective track events (5,6,7). To date, no literature has reported the energy system contribution to track running events utilising direct measurement of VO_2 during track running events, where velocity will not be constant.

Table 1 presents a review of the research reporting the results of aerobic and anaerobic energy system contributions to track running events from 100m to 5000m. Apart from research which has mathematically modelled energy system interaction, results in Table 1 were based on the measurement of VO_2 during treadmill running, while anaerobic metabolism was measured using either the AOD or $[La^-]_b$ methods. As seen, the range of percent contributions presented for the respective energy systems to track running is relatively large for most events. Disagreement between coaches, sports scientists and athletes over energy system contribution (16) is probably a result of the wide range of data available in textbooks and coaching manuals.

Thus, while individual athletic ability (performance) may alter the measured energetics of an event, the large range in estimated values currently makes it difficult to advise coaches and athletes on the likely aerobic/anaerobic energetics of these events. Combined with this range of estimates is also the lack of data collected during actual track running events. Hence, the aim of this series of studies was to quantify the relative aerobic and anaerobic energy system contribution to track running events between 100m and 3000m, during actual simulation of races on a synthetic athletics track. The principal objective of this research was to gauge the energetic contributions from as much ‘in-race’ data as possible.

Methods

Ten 3000m (8 male, 2 female), 14 1500m (10 male, 4 female), 11 800m (9 male, 2 female), 16 400m (11 male, 5 female), 13 200m (8 male, 5 female) and 15 100m (9 male, 6 female) athletes were recruited as subjects for these studies. Participants were trained track athletes, ranging from club to national level, who were specialists in the event/s they

Source	Gender	Event	Time (s)	Aer Cont	An Cont	Measure
Weyand et al. (1993) [6]	M	5000m	-	96	4	AOD – treadmill
Weyand et al. (1993) [6]	F	5000m	-	97	3	AOD – treadmill
di Prampero et al. (1993) [8]	M	3000m	452	89	11	M.Mod.
Peronnet and Thibault (1989) [9]	M	3000m	452	88	12	M.Mod.
Weyand et al. (1993) [6]	M	1500m	-	84	16	AOD – treadmill
Spencer and Gastin (2001) [5]	M	1500m	235	84	16	AOD – treadmill
Hill (1999) [7]	M	1500m	245	80	20	Race $[La^-]$b
di Prampero et al. (1993) [8]	M	1500m	209	78	22	M.Mod.
Peronnet and Thibault (1989) [9]	M	1500m	209	76	24	M.Mod.
Ward Smith (1985) [10]	M	1500m	218	72	28	M.Mod.
Bangsbo et al. (1993) [11]	M	3 min	180	78	22	AOD – treadmill
Weyand et al. (1993) [6]	F	1500m	-	87	13	AOD – treadmill
Hill (1999) [7]	F	1500m	308	83	17	Race $[La^-]$b
Weyand et al. (1993) [6]	M	800m	-	76	24	AOD – treadmill
Spencer and Gastin (2001) [5]	M	800m	113	66	34	AOD – treadmill
di Prampero et al. (1993) [8]	M	800m	102	62	38	M.Mod.
Craig and Morgan (1998) [12]	M	800m	115	61	39	AOD – treadmill
Lacour et al. (1990) [13]	M	800m		59	41	Race $[La^-]$b
Hill (1999) [7]	M	800m	120	58	42	Race $[La^-]$b
Peronnet and Thibault (1989) [9]	M	800m	102	57	43	M.Mod.
Ward Smith (1985) [10]	M	800m	105	52	48	M.Mod.
Weyand et al. (1993) [6]	F	800m	-	81	19	AOD – treadmill
Hill (1999) [7]	F	800m	145	62	38	Race $[La^-]$b
Weyand et al. (1993) [6]	M	400m	-	64	36	AOD – treadmill
Spencer and Gastin (2001) [5]	M	400m	49.3	43	57	AOD – treadmill
Hill (1999) [7]	M	400m	49.3	37	63	Race $[La^-]$b
Nummela and Rusko (1995) [14]	M	400m	49.5	37	63	AOD – treadmill
Peronnet and Thibault (1989) [9]	M	400m	44.1	30	70	M.Mod.
Lacour et al. (1990) [13]	M	400m		28	72	Race $[La^-]$b
Ward Smith (1985) [10]	M	400m	44.9	28	72	M.Mod.
van Ingen Schenau et al. (1991) [15]	M	400m	44.4	17	83	M.Mod.
Weyand et al. (1993) [6]	F	400m	-	66	34	AOD – treadmill
Hill (1999) [7]	F	400m	61.2	38	62	Race $[La^-]$b
Spencer and Gastin (2001) [5]	M	200m	22.3	29	71	AOD – treadmill
Ward Smith (1985) [10]	M	200m	20.4	14	86	M.Mod.
Peronnet and Thibault (1989) [9]	M	200m	19.8	14	86	M.Mod.
van Ingen Schenau et al. (1991) [15]	M	200m	20.0	8	92	M.Mod.
Peronnet and Thibault (1989) [9]	M	100m	9.8	8	92	M.Mod.
Ward Smith (1985) [10]	M	100m	10.0	7	93	M.Mod.
van Ingen Schenau et al. (1991) [15]	M	100m	9.8	4	96	M.Mod.

Legend: M- male, F- female, Aer cont.- % aerobic energy system contribution, An cont.- % anaerobic energy system contribution, AOD- accumulated oxygen deficit, M.Mod.- mathematical modelling.

Table 1: Summary of the relative anaerobic – aerobic % contribution to 100m to 5000m track events from simulated races and mathematical modelling measures.

acted as subjects in. Testing was performed in the Exercise Physiology Laboratory at the School of Human Movement and Exercise Science (HM and ES), University of Western Australia (UWA) and on an outdoor synthetic rubber (Rekortan) 400m athletic track.

Procedure Overview:

All subjects performed four testing sessions, separated by at least 48 hours and no more than 7 days, with time of day kept constant between testing sessions for each participant. Following initial familiarisation (test 1) with both the exercise protocol and Cosmed K4b^2 measuring equipment, a second testing session involved a graded incremental (motorised) treadmill test and a run to volitional exhaustion. The final two testing sessions involved participants performing a solo time trial run over their chosen athletic distance on an outdoor 400m synthetic athletics track. Subjects were asked to refrain from the ingestion of food or caffeine 2 hours prior to all testing sessions and from engaging in physical exercise in the 24 hours prior to testing. All testing took place during the competition phase of the local athletic season. Outdoor track testing sessions were postponed if climatic conditions were too extreme (40°C < Temp < 15°C, wind > 4 m/s-1 or raining).

Graded Exercise Test (GXT):

Following a standardised warm up of 5 min treadmill running (9 -10 km/h^{-1}) and a 5 min stretching period, subjects performed 6 - 9 stages of 4.5 - 7 min duration, separated by increasing recovery periods for each step of 4 - 7 min$^{(5)}$. The treadmill was maintained at a constant 1% gradient in order to account for the energy cost involved in over ground running$^{(17)}$, with initial velocities of 10 - 12 km/h-1 and final velocities of 16 - 18 km/h-1 (30% - 90% peak VO_2). During the exercise test, expired air was analysed with a breath-by-breath portable gas analyser (Cosmed K4b^2, Rome, Italy). Calibration of ventilation and fractional gas concentration measures was performed prior to each test in line with manufacturer's instructions. Following a 10 – 15 min recovery after the GXT, subjects completed an incremental run to volitional exhaustion, in order to elicit peak VO_2. This run began at the penultimate treadmill velocity achieved by the subject during the previous step test and the velocity was increased by 1 km/h^{-1} each min until the subject reached volitional exhaustion. An average of the highest values attained over any rolling one minute period was used as the peak VO_2 value.

Track sessions:

On arrival, the subject engaged in a standardised warm up consisting of several laps jogging and 10 - 20 min stretching. Following stretching, the Polar Heart rate monitor, Cosmed K4b^2 base harness and Cosmed K4b^2 system were attached to the subjects' torso. The subject then performed 3 - 4 x 90-100m "run throughs" at increasing speeds before calibration procedures were employed (as previously described for the GXT). Before commencement of the time trial, a pre-race capillary blood sample from an ear lobe was obtained for the measurement of $[La^-]_b$ (Accusport blood lactate analyser, Boehringer Mannheim, Mannheim, Germany)$^{(18)}$. Once the subject was prepared, measurement of VO_2 commenced and the subject proceeded to the start line where he/she was given standard starting commands, at which point the time trial began. Electronic infra-red timing systems (customised system, School of HM and ES, UWA, Perth, Australia) were located at the 400m (or start and finish line) and 200m (half lap) line and movement of the subject through the starting infra-red beam initiated the timing mechanism. The timing system enabled the measurement of split times and calculation of speed for each 200m as well as for the whole trial. Following completion of the time trial, Cosmed K4b^2 measurement was ceased and 1, 3, 5 and 7 min capillary blood samples from the ear lobe were obtained for the measurement of post exercise $[La^-]_b$. Finally, the Cosmed K4b^2 system was detached from the subject and gentle cool down exercise was allowed.

Calculation of relative energy expenditure: graded step test

For each subject, steady state (breath by breath) VO_2 data were averaged over the final minute of each step (Excel 10.0). A linear regression analysis was used on the collected step test data to determine the individual VO_2-velocity relationship for each subject, using custom written AOD determination software (Labview 5.1 National Instruments). This analysis allowed for the calculation of AOD (measured in ml O_2 equivalents/kg^{-1}) for each time trial from calculating the difference between the O_2 demand for the respective speed (from extrapolation of the calculated relationship) and the measured O_2 cost.

Calculation of relative energy expenditure: track session

For each subject, data from the fastest time trial were used in subsequent analysis. Cosmed $K4b^2$ breath by breath data was aligned to time trial start time in order to exclude data that were not collected during the time trial. Based on the predicted VO_2 from the individual VO_2 – velocity relationship determined from the GXT, VO_2, speed and time (over each 200m) were then used to calculate the AOD of each 200m component of the time trial. This allowed for a measurement of anaerobic (AOD) and aerobic (VO_2) energy contribution for each 200m throughout the run and a total contribution over the whole time trial. Gastin et al. (19) provided support for the application of AOD methodology to non-constant, all-out supra-maximal exercise, demonstrating no differences in the calculation of AOD between all out supra-maximal and constant intensity exercise.

Statistical Analysis:

Comparison across event distance and within event comparison of relative anaerobic energy percentage contributions, AOD, $[La^-]_b$ and peak race VO_2 were analysed by a two-way ANOVA. Significance was set a priori at the 0.05 level and all statistical analysis was conducted on SPSS statistical software (Version 10).

Results

Mean (+SD) and range of values for the aerobic and anaerobic energy contribution to all time trials is presented in Table 2. Mean (+SD) values for race time, peak race VO_2, peak [La-]b and AOD for all trials respectively are presented in Table 3. The interaction and change of the relative contribution by the anaerobic energy system throughout the duration of each trial is presented in Figure 1.

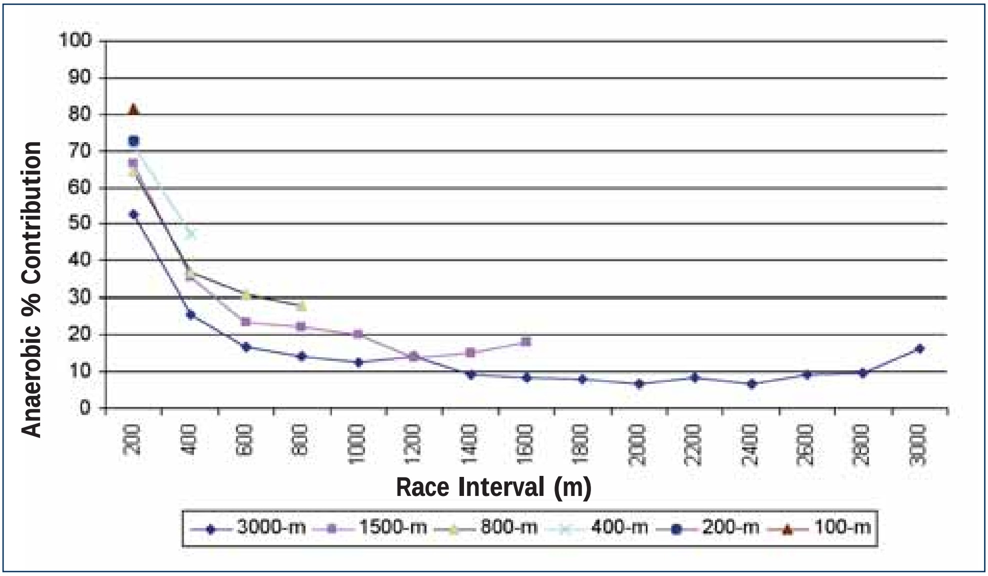

Figure 1: Relative contribution of the anaerobic energy system of male athletes in track running events between 100m and 3000m.

Discussion

It was the aim of these studies to quantify the relative aerobic and anaerobic energy system contribution during track running for events between 100m to 3000m.

As previous research on relative energy system contribution to track running has been based on duration of the trial as opposed to event distance, this research focused on the specifics of the event distance by performing measurements during track running. Coupled with this, trained track athletes were used as subjects, as opposed to untrained persons or athletes unfamiliar with these events. Calculation of the relative energy system contribution was enabled by the measurement of VO_2 during track time trials, combined with the measurement of anaerobic energy expenditure via AOD measures.

As expected, there was an increase in the relative aerobic energy system contribution as the event distance increased (as shown in Table 2). For male athletes there were no significant differences (p>0.05) between 3000m and 1500m anaerobic energy contributions, however, the 800m showed a significantly (p<0.05) increased anaerobic energy contribution than the 1500m. Following on, the 400m event also showed a significantly (p<0.05) increased anaerobic contribution

	Male		**Female**	
Event	% aerobic	% anaerobic	% aerobic	% anaerobic
3000m	**85.9** (+7.1)	**14.1** (+7.1)	**93.9** (+2.3)	**6.1** (+2.3)
1500m	**76.8** (+6.9)	**23.2** (+6.9)	**85.5** (+8.2)	**14.5** (+8.2)
800m	**60.3** (+9.0)	**39.7** [ab] (+9.0)	**70.1** (+16.2)	**29.9** (+16.2)
400m	**41.3** (+10.9)	**58.7** [abc] (+10.9)	**44.5** (+7.6)	**55.5** [abc] (+7.6)
200m	**28.4** (+7.9)	**71.6** [abc] (+7.9)	**33.2** (+8.0)	**66.8** [abc] (+8.0)
100m	**20.4** (+7.9)	**79.6** [abcd] (+7.9)	**25.0** (+7.4)	**75.0** [abcd] (+7.4)

Note: For each gender:
[a] significantly different from 3000m (p<0.05).
[b] significantly different from 1500m (p<0.05).
[c] significantly different from 800m (p<0.05).
[d] significantly different from 400m (p<0.05).
[e] significantly different from 200m (p<0.05).

Table 2: Mean (+SD) relative aerobic and anaerobic energy contribution to track events from 100m to 3000m in male and female track athletes

	Male				Female			
Event	Race time	Peak O$_2$	AOD	[La$^-$]b	Race time	Peak O$_2$	AOD	[La$^-$]$_b$
3000m	577.3 (+23.6)	64.12 (+8.12)	88.1 (+25.4)	8.6 (+2.1)	695.0 (+35.3)	53.86 (+6.02)	47.5 (+18.7)	8.1 (+2.6)
1500m	263.0^{a} (+8.3)	61.71 (+6.72)	71.0 (+24.8)	11.5 (+1.9)	316.7 (+6.9) a	50.23 (+6.33)	36.1 (+21.0)	10.6 (+0.4)
800 m	126.0^{ab} (+5.4)	55.81 (+7.86)	65.9 (+18.8)	12.4^{a} (+1.9)	151.5 (+4.9) ab	49.42 (+7.70)	43.8 (+29.6)	10.2 (+1.0)
400 m	52.2^{abc} (+1.9)	49.22^{ab} (+10.39)	48.0^{a} (+14.8)	13.9^{a} (+2.3)	60.2 (+4.1) abc	42.70 (+7.38)	41.8 (+10.5)	13.3 (+2.9)
200m	23.8^{abcd} (+1.1)	32.19^{abcd} (+7.31)	28.4^{abc} (+3.7)	10.4 (+3.0)	26.8^{abcd} (+1.2)	26.89^{abcd} (+12.25)	22.5 (+3.0)	10.8 (+2.3)
100m	11.5^{abcde} (+0.4)	17.85^{abcde} (8.53)	17.4^{abcd} (+4.4)	9.0^{d} (+1.5)	13.1^{abcde} (+0.5)	13.92^{abcd} (+7.09)	12.4 (+2.9)	8.7^{d} (+1.7)

Note: ^{a} significantly different from 3000m ($p<0.05$).
^{b} significantly different from 1500m ($p<0.05$).
^{c} significantly different from 800m ($p<0.05$).
^{d} significantly different from 400m ($p<0.05$).

Table 3: Mean (+SD) race time (s), peak race O$_2$ (ml.kg.-1min-1), accumulated oxygen deficit (AOD) (ml O$_2$ eq.kg-1) and peak post-race blood lactate concentration ([La-]b) (mmol.L-1) for male and female athletes for track events from 100m to 3000m.

compared to the 800m, however, while approaching significance, no difference was reported between the 200m and 400m events ($p = 0.06$). While the 100m event had the largest anaerobic contribution, which was significantly larger than the 400m event, no difference ($p>0.05$) was noted between the short sprint events (100m and 200m). Spencer and Gastin(5) reported similar findings for male track athletes during high-intensity treadmill runs, with large effect sizes indicating greater aerobic energy system involvement with increases in event distance from 200m to 1500m events. However, it must be noted that limitations on the AOD method are present during 100m and 200m sprints where exercise intensities are very high and durations are short. As a result it is likely that aerobic energy contribution was over estimated in these events.

Comparison of the anaerobic energy system contributions between events for female ath-

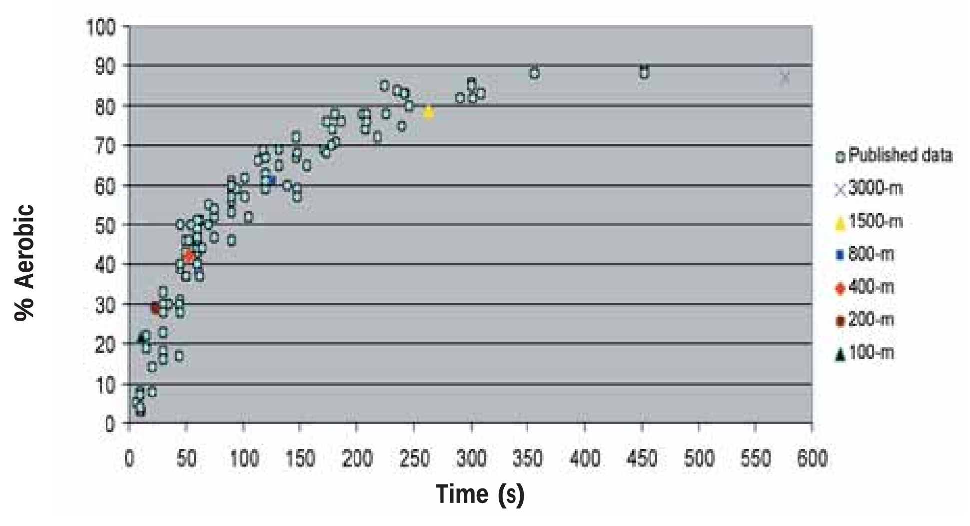

Figure 2: Summary of the relative contribution of the aerobic energy system to maximal exercise as reported by Gastin [(2)], with relative aerobic energy contributions to 100m through to 3000m track running events from the current study.

letes was restricted due to insufficient participant numbers in some events (particularly in the 3000m and 800m events where n = 2). While the expected trend of an increased aerobic contribution with increased event distance was evident, no significant differences were found between anaerobic energy contribution for 3000m, 1500m and 800m events. The 400m anaerobic energy contribution was significantly greater than the 800m, however, as with male athletes, there were no differences to the 200m event ($p>0.05$). Again, the 100m event also showed the largest relative anaerobic energy contribution, with no significant difference between the two shortest sprint events ($p>0.05$) (with the previous limitations reported for male athletes again relevant).

AOD measures for male track athletes were larger as the event distance increased, however, there were no significant differences found between 800m, 1500m and 3000m ($p>0.05$). Significant differences were evident between the shorter sprints and the longer distance events (100m and 200m with events longer than 800m, $p<0.05$). As a result of small subject numbers in the female events, some comparative statistical analysis was not conducted (3000m and 800m). As such, while no significant differences were noted ($p>0.05$), female AOD values became larger as the event distance increased until the 800m event, after which they reached a plateau. Spencer and Gastin[(5)] reported no significant difference between 800m and 1500m event AOD values. These results supported the findings of Medbø et al.[(4)], who had reported an exhaustion of the anaerobic capacity at about 2 min, hence a plateau in the AOD after events of this duration were expected. As outlined in Table 3, the highest post-race peak $[La^-]_b$ values also occurred in the sustained-sprint events of 400m and 800m. Accordingly, the peak $[La^-]_b$ values and plateau of AOD values after 800m corresponds to previous research reporting that in supra-maximal exercise, exhaustion of anaerobic energy production occurs by approximately 2 min[(4)].

The interaction of the aerobic and anaerobic energy systems has been outlined by Gastin (2001) as an important and until recently, misunderstood aspect of metabolic ATP production. He proposes that the involvement of oxidative metabolism is faster than the previously reported 2 – 3 min to reach equal contribution, stating that it occurs at about 75 sec. Following the time course of the involvement of the aerobic energy system based on the data from the track events conducted in the present study leads to similar conclusions. Figure 2 shows a reproduction of a similar figure produced by Gastin (2), outlining the relative time course of the involvement of the aerobic energy system to high-intensity exercise over a range of durations. Added into Figure 2 are the relative aerobic contributions based on AOD measures for each of the track events involved in the present study. Data points for all event distances fall within the depicted general trend of the aerobic energy contribution to maximal exercise.

As seen in Figure 1, during the 1500m and 3000m events, the aerobic and anaerobic energy systems show a cross over in dominance between the respective systems by 200m (~30 sec). During the faster sprint-endurance events, a cross over point occurs between the 200- and 400m mark (~40 - 55 sec). This cross over point indicates that at that particular point in time, the aerobic energy system contributes equally to the overall energy supply. After peaking within the first 5 – 10 sec, the powerful anaerobic metabolic supply declines exponentially with time, as concurrently the less powerful process of oxidative metabolism is still increasing. Hence, the actual point where both systems have contributed an equal contribution to the total energy supply does not occur until later than the 30 – 40 sec cross over point (as represented in Figure 1). Rather, this point of equal total contribution is likely to occur around the 70 – 80 sec mark, which is similar to the time point proposed by Gastin(2). It must also be noted that during the final 200m of the 1500m and 3000m time trials there is an increased reliance on anaerobic metabolism with increased race velocities. With increased running speeds during the final portion of the race, often involving sprint finishes, there will be a slightly increased demand for anaerobic ATP production.

Accordingly, with the accurate profiling of the relative contribution and interaction of energy systems in track events, coaches (particularly middle distance coaches) can confirm that training programmes are tailored towards the specific requirements of an event. As such, knowledge of event energetics allows for both specific sessions and the overall training structure to be designed to replicate the specific event requirements. Included within this training plan is the relative allocation of the necessary time in order to develop the important components specific to each event. Furthermore, any improvements in the interaction of the energy systems via improvements in the speed of the response of respective energy systems may also be of importance (dependent on specific event requirements).

Conclusion

In conclusion, this series of studies determined the aerobic – anaerobic energy system contribution to track running events (for males and females) of 3000m as 86% - 14% and 94% - 6% respectively, 1500m as 77% - 23% and 86% - 14%, 800m events as 60% - 40% and 70 - 30%, 400m as 41% - 59% and 45% - 55%, 200m as 28% - 72% and 33% - 67% and finally 100m as 20% - 80% and 25% - 75%. This data fits well with recent previous research into the energetics of track events of these distances and provides specific applied information as to both the role and interaction of the respective metabolic pathways throughout track events from 100m to 3000m. While training status, performance and ability of an athlete may alter the energetics of any event, the use of specific track run data allows for a more relevant measurement of the relative energy system contributions to these events. Also, these studies highlight and confirm previous research outlining both the significance of and speed at which the aerobic energy system becomes involved in maximal exercise between 11 sec and 10 min. This information may be helpful to coaches and sports scientists alike for the further understanding of event energetics and it's application in the correct planning and implementation of training programmes to achieve peak athletic performance.

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