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Abstract: As a wide range of values have been suggested for the relative energetics of 400-m and 800-m track running events, this study aimed to quantify the respective aerobic and anaerobic energy contribution to these events during actual track running. Sixteen trained 400-m (11 male, 5 female) and 11 trained 800-m (9 male and 2 female) athletes acted as subjects for this study. Subjects performed (on separate days) a laboratory graded exercsie test and multiple race time trials. The relative energy system contribution was calculated by multiple methods based upon measures of race O2, Accumulated Oxygen Deficit (AOD), blood lactate and estimated phosphocreatine degradation (La/PCr). Aerobic -€“ anaerobic energy system contribution (AOD method) to the 400-m event was calculated as 41% - 59% (male) and 45% - 55% (female). For the 800-m event, an increased aerobic involvement was noted with a 60% - 40% (male) and 70% - 30% (female) respective contribution. Significant (p<0.05) negative correlations were noted between race performance and anaerobic energy system involvement (La/PCr) for male 800-m and female 400-m events (r = -0.77 and -0.87 respectively). This data collected during actual track running compares well with previous estimates of the relative energy system contributions to 400-m and 800-m events. Additionally, the relative importance and speed of interaction of the respective metabolic pathways has implications to training for these events.

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ENERGY SYSTEM CONTRIBUTION TO 400-m AND 800-m TRACK RUNNING.

Running Title: Energy systems in track running.

ABSTRACT:

As a wide range of values have been suggested for the relative energetics of 400-m and 800-m track running events, this study aimed to quantify the respective aerobic and anaerobic energy contribution to these events during actual track running. Sixteen trained 400-m (11 male, 5 female) and 11 trained 800-m (9 male and 2 female) athletes acted as subjects for this study. Subjects performed (on separate days) a laboratory graded exercsie test and multiple race time trials. The relative energy system contribution was calculated by multiple methods based upon measures of race $\dot{V}O_2$, Accumulated Oxygen Deficit (AOD), blood lactate and estimated phosphocreatine degradation (La/PCr). Aerobic – anaerobic energy system contribution (AOD method) to the 400-m event was calculated as 41% - 59% (male) and 45% - 55% (female). For the 800-m event, an increased aerobic involvement was noted with a 60% - 40% (male) and 70% - 30% (female) respective contribution. Significant ($p<0.05$) negative correlations were noted between race performance and anaerobic energy system involvement (La/PCr) for male 800-m and female 400-m events ($r = -0.77$ and -0.87 respectively). This data collected during actual track running compares well with previous estimates of the relative energy system contributions to 400-m and 800-m events. Additionally, the relative importance and speed of interaction of the respective metabolic pathways has implications to training for these events.

Key Words:

Accumulated Oxygen Deficit, anaerobic energy system measurement, athletics, middle distance running, sprint running.

INTRODUCTION:

The relative interaction of the respective metabolic pathways for the provision of ATP during different stages of sustained high intensity exercise is of importance to understanding the metabolic demands of an athletic event. This knowledge is useful for aiding the correct implementation of training programs designed to optimise the metabolic production of ATP and hence achieve peak performance. This particularly applies to events that fall within exercise durations that rely heavily upon both anaerobic and aerobic metabolism for energy production. 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 400-m and 800-m track races, lasting from over 40 s to 2 min (depending on ability), fall within the category of demanding heavy reliance on all three energy pathways. 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.

Information is available on the respective energy system involvement to exercise of 30 s and longer (Medbø and Tabata 1989, Bogdanis et al. 1995, Pripstein et al. 1999), with recent research focusing on running distances of 400-m and 800-m in length (Hill 1999, Spencer and Gastin 2001). However, no research has assessed the $\dot{V}O_2$ of these events during actual track races, rather, it has focussed on simulation of such events with laboratory treadmill runs. Regardless of the lack of track specificity, within this body of

laboratory based research, a wide range of values still exists on the estimated contribution of the respective energy systems to 400-m and 800-m track races. As Table 1 indicates, the anaerobic energy contribution to the 400-m event has been estimated to range from 36% to double that at 72%, while the estimated anaerobic energy contribution to the 800-m event is more concise, with estimates ranging from 27% to 42%.

Methods used to estimate energy system contribution to track running events have generally utilised measures of $\dot{V}O_2$ during simulated event duration treadmill running, while using either accumulated oxygen deficit (AOD) measures or glycolyitc activity from blood lactate ($[La^-]_b$) concentrations to estimate anaerobic energy contribution. However, as yet no research has measured both the $\dot{V}O_2$ response and anaerobic energy system involvement during track running events. Weyand et al. (1993), Nummela and Rusko (1995), Craig and Morgan (1998) and Spencer and Gastin (2001) all used treadmill running to simulate the respective track events and estimated anaerobic involvement via the application of AOD measures, based on the methodology of Medbø et al. (1988). Hill (1999) used treadmill running to measure $\dot{V}O_2$ during runs of similar durations to 400-m and 800-m track events, while applying the energetic calculations proposed by di Prampero (1981) to calculate anaerobic energy system contribution from peak post competition race $[La^-]_b$. Similarly, Lacour et al. (1990) also used post race peak $[La^-]_b$ values to estimate anaerobic energy involvement. However, as $\dot{V}O_2$ was not measured, an assumed efficiency for running was used to estimate the energetic contribution of the aerobic system.

While individual athletic ability and hence performance will change the measured energetics of the 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 400-m and 800-m track running events. Hence the aim of this research was to quantify the relative aerobic and anaerobic energy contribution to 400-m and 800-m track running events, during actual simulation of races on a synthetic athletic track. The principal objective of this research was to gauge the energetic contributions from as much 'in race' data as possible. Estimation of the respective energy pathways was conducted by measurement of race $\dot{V}O_2$, AOD, race $[La^-]_b$ and estimated phosphocreatine (PCr) contribution.

METHODS:

Subjects:

Trained male (n=11) and female (n=5) 400-m and male (n=9) and female (n=2) 800-m track athletes (descriptive characteristics are presented in Table 2) volunteered for this study. Each subject gave his or her written consent prior to engaging in any testing procedures. Subjects ranged in ability from Club level to National level athletes. Testing was performed both 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) 400-m athletic track. Ethical approval for testing was granted by the Human Ethics Committee of UWA.

Procedure Overview:

All subjects performed four testing sessions, separated by at least 48 h 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 step test and a run to volitional exhaustion. Included in this second session were anthropometric measures for estimation of muscle mass (Martin et al. 1990), consisting of body mass, height, forearm, thigh and calf girths and thigh and calf skinfolds. The final two testing sessions involved participants performing a solo time trial run over their chosen athletic distance (either 400-m or 800-m) on an outdoor 400-m synthetic athletic track. Subjects were asked to refrain from the ingestion of food or caffeine 2 – 3 h prior to all testing sessions and from engaging in physical exercise in the 24 h 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 ($40^oC <$ Temp $< 15^oC$, wind > 4 m·s^{-1} or raining).

Graded Exercise Test:

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 each step of 4 - 7 min (Spencer and Gastin 2001). The treadmill was maintained at a constant 1% gradient in order to account for the energy cost involved in over ground running (Jones and Doust 1996), with initial velocities of 10 - 12 km·h^{-1} and final velocities of 16 - 18 km·h^{-1} (30% - 90% peak $\dot{V}O_2$). During the exercise

test, expired air was analysed with a breath-by-breath portable gas analyser (Cosmed K4b^2, Rome, Italy). Calibration of the Cosmed turbine with a 3 L syringe and gas analysers with an alpha verified beta calibration gas (BOC gases, Perth, Australia) both occurred in line with manufacturer's instructions at the commencement of each individual step of the GXT.

Following the completion of the warm up and initial calibration procedures, the heart rate monitor (Polar Accurex Plus, Kempele, Finland) and Cosmed K4b^2 base harness were arranged on the subject and the Cosmed K4b^2 system was attached to the subject's torso. Subjects then stepped onto the moving belt of the treadmill at the selected initial speed. At the completion of the step, the treadmill was stopped, Cosmed K4b^2 measurement ceased and re-calibration procedures (as previously mentioned) were conducted prior to the commencement of the next step. Following completion of the final stage, subjects were allowed a recovery period of 10 -15 min before completing an incremental run to volitional exhaustion, in order to elicit peak $\dot{V}O_2$. 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-min period was used as the peak $\dot{V}O_2$ value.

Track sessions:

On arrival, the subject engaged in a standardised warm up consisting of several laps jogging, 10 - 20 min stretching and 3 - 4 x 90-100 m "run throughs" at increasing speeds.

Following stretching, the Polar Heart rate monitor and Cosmed K4b^2 base harness were arranged on the subject and the Cosmed K4b^2 system was attached to the subject's torso. The Subject then performed the run throughs before calibration procedures were employed (as previously described for graded step test). 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, Boehinger Mannheim, Mannheim, Germany) (Fell et al. 1998). Once the subject was prepared measurement of $\dot{V}O_2$ commenced and the subject proceeded to the start line. The period from the commencement of Cosmed K4b^2 measurement to the start of the time trial was timed in order to locate the exact start of the time trial on the data file. Prior to commencement of the trial, the subject was given standard instructions pertaining to the need for maximal effort throughout the trial. At the start line, the subject was given the standard starting commands, at which point they approached the start line and then began the time trial. Electronic infra-red timing systems (customised system, School of HM and ES, UWA, Perth, Australia) were located at the 400-m (start/finish) and 200-m (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 200-m 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) $\dot{V}O_2$ data were averaged over the final minute of each step (Excel 10.0). Pinnington et al. (2001) have previously reported increased Cosmed K4b^2 measures of $\dot{V}O_2$ when compared to measures from a laboratory metabolic cart. Hence, prior to analysis, Cosmed K4b^2 $\dot{V}O_2$ data were corrected using regression equations that were calculated based on previous research conducted in our laboratory using high intensity 1, 3 and 10 min treadmill runs [regression equation: $\dot{V}O_2$ = 0.926 · Cosmed $\dot{V}O_2$ – 0.227, r^2 = 0.84 (Duffield et al. 2001)]. A linear regression analysis was used on the collected step test data to determine the individual $\dot{V}O_2$-velocity relationship for each subject, using custom written AOD determination software (Labview 5.1 National Instruments). This analysis allowed for the calculation of AOD 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.

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. The 200-m split times allowed the calculation of $\dot{V}O_2$ consumed during each 200-m portion of the event. As Cosmed K4b^2 software reports $\dot{V}O_2$ data each breath in ml·min^{-1}, an average $\dot{V}O_2$ was calculated based on all breaths collected during each individual 200-m segment (Excel 10.0). This was then converted into a total VO_2 (L) consumed for each 200-m, based on the respective

time taken to complete the 200-m split. Based on the predicted $\dot{V}O_2$ from the individual $\dot{V}O_2$ – velocity relationship determined from the GXT, corrected VO_2, speed and time were then used to calculate the AOD of each 200-m component of the time trial (using custom written AOD determination software, Labview 5.1 National Instruments). This allowed for a primary measurement of anaerobic and aerobic energy contribution to each 200-m through out, and a total contribution over the whole time trial. Gastin et al. (1995) provided support for the application of AOD methodology to non-constant, all-out high intensity exercise, demonstrating no differences in the calculation of AOD between all out sustained high intensity and constant intensity exercise.

Accumulated $[La^-]_b$ and estimated PCr degradation, in conjunction with AOD measures, were used as a secondary method to determine anaerobic energy contribution based on data collected during a track based time trial. Glycolytic energy contribution based on $[La^-]_b$ accumulation was calculated according to di Prampero (1981) as 3.0 ml O_2 equivalents$\cdot kg^{-1}$ body mass for each 1 mmol$\cdot l^{-1}$ increase in $[La^-]_b$ above pre exercise levels. Phosphocreatine store contribution was calculated as 37.0 ml $O_2 \cdot kg^{-1}$ muscle mass (di Prampero 1981). Muscle mass was estimated according to Martin et al. (1990) using forearm, thigh and calf girths and skinfolds. Therefore, a second measure of anaerobic energy contribution (AOD being the first) was obtained by the addition of ml$\cdot$kg of O_2 equivalents determined from $[La^-]_b$ and PCr stores respectively (as used by Hill 1999). As a result of flaws in the use of $[La^-]_b$ as a quantitative tool for the measurement of anaerobic energy supply (Hermansen and Vaage 1977, Green and Dawson 1993), La/PCr measures in the present study were incorporated as a secondary, in race measure of

anaerobic contribution. Percentage anaerobic (and aerobic) energy contribution to each event was then calculated as the total estimated anaerobic energy output divided by the total energy utilised during the trial. This calculation was conducted for both the AOD measure and also the (La/PCr) measure of anaerobic energy supply.

Statistical Analysis:

Comparison across event distance and within event comparison of total anaerobic energy expenditure and relative anaerobic energy percentage contributions for the male athletes were analysed by a one way ANOVA (data from female analysis was excluded prior to analysis because of a small sample size). Relationships between event performance and measured parameters were analysed by a Pearson's correlation coefficient (female 800-m data was excluded prior to analysis). Significance was set apriori 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 400-m and 800-m time trials calculated by both AOD and La/PCr methods are presented in Table 3. Mean (±SD) values for race time, peak heart rate, peak race $\dot{V}O_2$, peak $[La^-]_b$, AOD, total energy costs and average speed for 400-m and 800-m trials respectively are presented in Table 4. The interaction and change of the relative contribution by the aerobic and anaerobic energy systems throughout the duration of the 400-m and 800-m trials are presented in Figures 1 and 2.

A significant difference ($p<0.05$) was revealed in the anaerobic energy contribution between male 400-m and 800-m trials for both measurement methods (AOD and La/PCr), with larger anaerobic energy contributions in the 400-m trial. No significant differences ($p>0.05$) were revealed between male 400-m and 800-m trials for AOD, peak race $\dot{V}O_2$, % of peak $\dot{V}O_2$, peak $[La^-]_b$, peak race heart rate or total energy cost ($ml\ O_2 \cdot kg^{-1} \cdot m^{-1}$).

No significant differences ($p>0.05$) were revealed in the calculated relative anaerobic energy contribution due to measurement technique (AOD vs La/PCr) for either male event. However, only the 400-m male trial showed any correlation for anaerobic energy contribution between AOD and La/PCr measures ($r = 0.82$, $p<0.01$).

No significant correlations ($p<0.05$) were evident between either male or female 400-m race performance and peak race $\dot{V}O_2$, peak race heart rate, AOD, % anaerobic energy contribution (AOD), peak $[La^-]_b$, anaerobic energy total (La/PCr), male % anaerobic energy contribution (La/PCr) or peak $\dot{V}O_2$. No significant correlations ($p<0.05$) were also evident between male 800-m race performance and peak race $\dot{V}O_2$, peak race heart rate, AOD, % anaerobic energy contribution (AOD), peak $[La^-]_b$, anaerobic energy total (La/PCr) or peak $\dot{V}O_2$. Finally, performance (race time) in the male 800-m and female 400-m trials was strongly negatively correlated with the anaerobic energy contribution based on La/PCr measures (- 0.77 and - 0.87 respectively, $p<0.05$).

DISCUSSION:

The aim of the current research was to quantify the respective energy system contribution in 400-m and 800-m track running events from specific 'in race' measures. As a secondary objective, the relationships between measured and calculated physiological race variables and performance were examined. Results indicated a predominance of anaerobic energy supply during the 400-m trial with an aerobic metabolic dominance during the 800-m, regardless of measurement technique. While this finding held for both genders, male athletes tended to have a greater anaerobic energy supply than female athletes for both events, possibly due to either the somewhat shorter duration of their respective runs or the higher running velocities reached by the male athletes.

The present study estimated anaerobic energy contributions from AOD and La/PCr measures in the 400-m trial as 59% and 65% for males and 55% and 63% for females respectively. Previous data indicated a range between 36% to 72% for male athletes (Lacour et al. 1990, Weyand et al. 1993, Hill 1999 and Spencer and Gastin 2001). An anaerobic energy contribution of 62% is the only value reported involving female athletes (Hill 1999). Recent research by Hill (1999) and Spencer and Gastin (2001), who performed laboratory treadmill runs (rather than track running), reported 68% and 57% anaerobic energy contributions respectively for male subjects. The current data compare favourably with these estimates, indicating a likely anaerobic energy contribution of around 60% to 400-m events. Anaerobic energy estimates for 800-m track events have ranged between 27% and 42%, with Hill (1999) reporting a 42% and 38% contribution for males and females respectively, and Spencer and Gastin (2001) estimating a 34%

contribution for males. Again, the present data fit well with the these estimates, with AOD and La/PCr measures indicating a 40% and 37% contribution for male 800-m athletes and a 30% and 31% contribution for female athletes.

While the overall contribution of the respective metabolic pathways for the supply of ATP is of some practical training significance, their interaction and involvement over the course of the event is also of importance. Early research (Bouchard et al. 1991) suggested a predicted 'crossover point' where the relative dominance of the energy systems changes, indicating when aerobic metabolism becomes the predominant metabolic supplier. This crossover point has been reported as being 2 min in duration (Astrand and Rohdahl 1986, Fox 1993). However, based on the results of recent published reports, this now seems doubtful. Gastin (2001) and Spencer and Gastin (2001) reported that the crossover occurred within 30 s of the start of exercise and that the aerobic energy system was dominant thereafter (as a % of energy supply during individual 5 s time intervals). From our previous 1500-m and 3000-m data (Duffield et al. 2002), it was noted that the crossover point between aerobic and anaerobic energy supply occurred by the 200-m mark, essentially 30 – 35 s into the event. As seen in Figures 1 and 2, a crossover point occurs following the completion of 200-m, essentially during the 200 to 400-m interval, or approximately 40 - 55 s into the trial. While comparatively slower than the cross over point reported in the data of Spencer and Gastin (2001), when compared to the 1500/3000-m data, the higher velocities and hence larger anaerobic energy contributions noted in the current study may have delayed the point of dominance of the aerobic system. Regardless, it is evident that the speed of the involvement of the aerobic energy

system, even to events of a relatively short duration and high intensity, is faster than previously thought to be the case.

A potentially important aspect for performance may relate to the speed of the $\dot{V}O_2$ response. Rossiter et al. (2002) have provided evidence for a connection between the speed of the $\dot{V}O_2$ response and a temporal alignment to the intramuscular breakdown of PCr, indicating that a faster degradation of PCr stores may lead to an increased speed of the $\dot{V}O_2$ response. Thus, high intensity interval training may potentially improve both anaerobic ability (via improvements or enhancement of enzymatic activity and hence PCr hydrolysis) and aerobic ability (via improvement of the rate of energy supply from aerobic metabolism). While other training stimuli, specific to each event, are also important for success (ie. peak running velocity, muscle buffer capacity or aerobic capacity), training designed to improve the speed of involvement of each pathway may be of importance to improve 400-m or 800-m track performance. Similarly, pacing strategies employed in 800-m events may benefit from such information. As Bishop et al. (2001) have shown, faster all out starts in 2 min kayak ergometer performance resulted in an improved performance. Faster starting strategies may provide both an increased anaerobic energy contribution plus a possible faster $\dot{V}O_2$ kinetic response. This has also recently been demonstrated by Gardner et al. (2003), where faster $\dot{V}O_2$ kinetics were reported in faster self-paced starts in all-out 2 min exercise when compared to constant cadence cycle ergometry tests. Hence faster starting velocities before settling into an even pace for the body of the race, may help improve 800-m race performance (in so far

as excessive accumulation of performance hindering metabolic waste products as a result of glycolysis are not present).

No statistical difference ($p<0.05$) was evident for the energy cost relative to distance (ml $O_2 \cdot kg^{-1} \cdot m^{-1}$) between male 400-m and 800-m trials and while not statistically analysed, a trend was evident for lowered (more efficient) values for females when compared to the male athletes. Hill (1999), while reporting no difference in the energy cost of either 400-m or 800-m events due to gender, made the comment that this may change if the respective athletes were matched for speed or duration as opposed to distance of the event. Energy costs for male 400-m and 800-m athletes here were similar to those reported by Hill (1999) (0.205 and 0.198 ml $O_2 \cdot kg^{-1} \cdot m^{-1}$ respectively). However, female values were somewhat lower in the present study than reported by the same author (0.211 and 0.202 ml $O_2 \cdot kg^{-1} \cdot m^{-1}$ for 400-m and 800-m respectively). Similar to results of both Hill (1999) and Lacour et al. (1990), who predicted values based on assumed efficiency data, energy costs here tended to be higher for the shorter, faster events, indicating a lowered efficiency during faster velocity runs.

Again, while the overall contribution of the respective metabolic pathway supply of ATP has practical training significance, the relationship between physiological measures and performance is also of importance. If a physiological measure (or what it represents) is a determinant of performance, then regardless of the overall energy system contribution, this measure will be an important factor for any training program. Correlations between measured and calculated physiological variables and 400-m or 800-m performance did

indicate that the male 800-m and female 400-m trial performances were strongly correlated ($p<0.05$) with the anaerobic contribution calculated from La/PCr estimates (-0.77 and –0.87). Due to the predominance of the anaerobic energy systems in the 400-m event and an extensive utilisation of the anaerobic energy supply in the 800-m event, strong correlations with performance are not unexpected. Both Hill (1999) and Lacour et al. (1990) reported strong correlations ($r = >0.76$) between 400-m performance and peak $[La^-]_b$ values. Accordingly, the ability to utilise the anaerobic capacity may directly relate to high-intensity track performance, as the rate at which an athlete can supply ATP via anaerobic sources in these types of events will influence the power output and hence velocity maintained (Hirvonen et al. 1987, Lacour et al. 1990, Linossier 1992).

While previous research (Ramsbottom et al. 1993, Craig and Morgan 1998) has reported significant relationships between maximal AOD and 800-m running performance, there was no correlation between AOD measures of the 800-m (or 400-m) trial and performance in the current study ($p>0.05$). Previous research has compared maximal laboratory based measures of AOD to track performances. These measures have utilised longer duration, constant velocity, exhaustive exercise, often with higher treadmill gradients and hence greater muscle mass recruitment. Maximal AOD may be correlated to middle distance running performance, however, the present study correlated the AOD utilised during the actual trial with subsequent performance and found no relationship ($p>0.05$). An exercise duration of 120 s has been reported as the duration required to exhaust the anaerobic capacity (Medbø et al. 1988). As such, in the present study, the 400-m event may have been of insufficient duration, while the 800-m was possibly not of

a sufficient intensity for the entire event to induce total exhaustion of the anaerobic capacity. If it were the case that the 800-m trial did not result in a maximal use of the AOD, possibly due to the nature of the individual time trial, this may explain the lack of a significant correlation between time trial (non-maximal) AOD and performance.

Finally, anaerobic energy system contribution calculated from estimates of La/PCr utilisation correlated with male 800-m and female 400-m track performances. However, both peak $[La^-]_b$ and anaerobic contribution from AOD measures did not correlate significantly to performance for either of the respective track events. ANOVA results indicated no significant differences between the calculated anaerobic energy contribution between either (male) event, however, only the 400-m measures of AOD and La/PCr correlated significantly ($p<0.05$). $[La^-]_b$ values reported in previous literature for 400-m and 800-m events have ranged between 14 to 18 $mMol \cdot L^{-1}$ (Lacour et al. 1990, Hill 1999, Nummela and Rusko 2000) which are greater than the values recorded in the present study. However, given that the present study involved a solo time trial and that previous research has reported post-competition $[La^-]_b$ values, this result is not unexpected. It is also worth mentioning that AOD measures are generally accepted as the criterion measure of anaerobic energy expenditure as a result of flaws in the use of $[La^-]_b$ as a quantitative tool for the measurement of anaerobic energy supply (Hermansen and Vaage 1977, Green and Dawson 1993). The current research calculated the anaerobic metabolic expenditure based upon AOD as the primary measure, which, while still having its own inherent assumptions and limitations (Gastin et al. 1995) is currently the most popular technique for measurement of anaerobic energy expenditure. As previous research has

shown a lack of association between measures of $[La^-]_b$ and anaerobic energy system based on AOD (Medbø 1987), La/PCr measures in the present study were incorporated as a secondary, in race measure of anaerobic contribution.

In conclusion, the current research determined the aerobic – anaerobic energy system contribution (AOD method) to track running events of 400-m (for male and female athletes) as 41% - 59% and 45% - 55% and for 800-m trials as 60% - 40% and 70 - 30% respectively. These data fit well with the results of recent research into the energetics of simulated track events of these distances while providing information as to both the role and interaction of the respective metabolic pathways throughout either event. In addition, physiological parameters that correlated with track performance have also been identified, which in conjunction with the data on individual event energetics, can be applied to training programs in order to assist in the achievement of peak athletic performance.

REFERENCES:

Astrand.P-O. and Rodahl.K. (1986) Textbook of Work Physiology. 3rd^{d} Ed. New York: McGraw – Hill.

Bishop.D., Bonetti.D. and Dawson.B. (2001) The influence of pacing strategy on VO_2 and supramaximal kayak performance. Medicine and Science in Sports and Exercise. 34(6): 1041 – 1047.

Bogdanis.G.C., Nevill.M.E., Boobis.L.H., Lakomy.H.K.A. and Nevill.A.M. (1995) Recovery of power output and muscle metabolites following 30 s of maximal sprint cycling in man. Journal of Physiology. 482: 467 – 480.

Bouchard.C., Taylor.A.W., and Simoneau.J (1991) Testing anaerobic power and capacity. In MacDougall.J.D., Wenger.H.A. and Green.H.J (Ed). Physiological Testing of the High Performance Athlete. Champaign (IL): Human Kinetics.

Craig.I.S. and Morgan.D.W. (1998) Relationship between 800-m running performance and accumulated oxygen deficit in middle-distance running. Medicine and Science in Sports and Exercise. 30 (11): p1631 – 1636.

di Prampero. P.E. (1981) Energetics of muscular exercise. Review of Physiology, Biochemistry and Pharmacology. 89: 143 - 223.

Duffield.R., Dawson.B., Pinnington.H. and Wong.P. (2001) Accuracy and reliability of a Cosmed K4b^{2} portable gas analyser. Conference Abstracts. Australian Conference of Science and Medicine in Sport. Perth, W.A. ISBN 1875334106:67.

Duffield.R., Dawson.B. and Goodman.C. (2002) Energy system contribution to 1500 m and 3000 m track running events. Proceedings 7th Annual Congress of the European College of Sports Science. Athens 24 – 28 July 2002. 2: O752.

Fell.J.W., Rayfield.J.M., Gulbin.J.P. and Gaffney.P.T. (1998) Evaluation of the Accusport lactate analyser. International Journal of Sports Medicine. 19: 199 – 204.

Fox.E.L., Bowers.R.W., Foss.M.L. (1993) The Physiological Basis for Exercise and Sport. 5th Ed. Dubuque IA: WCB.

Gaitanos.G.C., Williams.C., Boobis.L.H. and Brooks.S. (1993) Human muscle metabolism during intermittent maximal exercise. Journal of Applied Physiology. 75(2): 712 – 719.

Gardner.A., Osborne.M., D'auria.S. and Jenkins.D. (2003) A comparison of two methods for the calculation of accumulated oxygen deficit. Journal of Sports Sciences. 21: 155 – 162.

Gastin.P.B. (2001) Energy system interaction and relative contribution during maximal exercise. Sports Medicine. 31(10): 725 – 741.

Gastin.P.B., Costill.D.L., Lawson.D.L., Krzeminski.K. and McConnell.G.K. (1995) Accumulated oxygen deficit during supramaximal all out and constant intensity exercise. Medicine and Science in Sports and Exercise. 27: 255 –263.

Green.S. and Dawson.B. (1993) Measurement of anaerobic capacities in humans; definitions, limitations and unsolved problems. Sports Medicine. 15(5): 312 - 327.

Hill.D.W. (1999) Energy system contributions in middle-distance running events. Journal of Sports Sciences. 17: 477 – 483.

Hirvonen.J., Nummela.A., Rusko.H., Rehunen.S. and Harkonen.M. (1987) Fatigue and changes of ATP, creatine phosphate and lactate during the 400-m sprint. Canadian Journal of Sports Science. 17(2): 141 – 144.

Hermansen.L. and Vaage.O. (1977) Lactate disappearance and glycogen synthesis in human muscle after maximal exercise. American Journal of Physiology. 233: 422 – 429.

Jones.A.M. and Doust.J.H. (1996) A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. Journal of Sports Sciences. 14: 321 – 326.

Lacour.J.R., Bouvat.E. and Dormois.D. (1990) Post-competition blood lactate concentrations as indicators of anaerobic energy expenditure during 400-m and 800-m races. European Journal of Applied Physiology. 61: 172 – 176.

Martin.A.D., Spenst.L.F., Drinkwater.D.T. and Clarys.J.P. (1990) Anthropometric estimation of muscle mass in men. Medicine and Science in Sports and Exercise. 22: 729 – 733.

Medbø.J.I. (1987) Is the blood-lactate concentration an accurate measure of anaerobic metabolism during exercise in man? Journal of Physiology. 390: 134P.

Medbø.J.I., Mohn.A.C., Tabata.I., Bahr.R. and Vaage.O. (1988) Anaerobic capacity determined by maximal accumulated O_2 deficit. Journal of Applied Physiology. 64: 50 – 60.

Medbø.J.I. and Tabata.I. (1989) Relative importance of aerobic and anaerobic energy release during short-lasting exhausting bicycle exercise. Journal of Applied Physiology. 67(5): 1881 – 1886.

Nummela.A. and Rusko.H. (1995) Time course of anaerobic and aerobic energy expenditure during short term exhaustive running in athletes. International Journal of Sports Medicine. 16(8): 522 – 527.

Nummela.A. and Rusko.H. (2000) Acclimatisation to altitude and normoxic training improve 400-m running performance at sea level. Journal of Sports Sciences. 18: 411 – 419.

Pripstein.L.P., Rhodes.E.C., McKenzie.D.C. and Coutts.K.D. (1999) Aerobic and anaerobic energy during a 2-km race simulation in female rowers. European Journal of Applied Physiology. 79: 491 – 494.

Ramsbottom.R., Nevill.A.M., Nevill.M.E., Newport.S. and Williams.C. (1994) Accumulated oxygen deficit and short distance running performance. Journal of Sports Sciences. 12: 447 – 453.

Rossiter.H.B., Ward.S.A., Kowalchuck.J.M., Howe.F.A., Griffiths.J.R. and Whipp.B.J. (2002) Dynamic asymetry of phosphocreatine concentration and oxygen uptake between the on- and off- transients of moderate and high intensity exercise in humans. Journal of Physiology. 541: 991 –1002.

Spencer.M.R. and Gastin.P.B. (2001) Energy system contribution during 200- to 1500-m running in highly trained athletes. Medicine and Science in Sports and Exercise. 33(1): 157 – 162.

Weyand.P., Cureton.K., Conley.D. and Sloniger.M. (1993) Percentage anaerobic energy utilized during track running events. Medicine and Science in Sports and Exercise. 25:S105.

Table 1: Relative % aerobic – anaerobic contribution to 400-m and 800-m track events and measurement methods used.

Source	Event	Aerobic contribution	Anaerobic contribution	Measurement
Weyand et al. (1993).	400	64	36	Treadmill (AOD)
Spencer and Gastin (2001).	400	43	57	Treadmill (AOD)
Numela and Rusko (1995).	400	37	63	Treadmill (AOD)
Hill (1999).	400	32	68	Treadmill and race $[La^-]_b$
Lacour et al. (1990).	400	28	72	Race $[La^-]_b$, assumed efficiency
Craig and Morgan (1998).	800	73	27	Treadmill (AOD)
Weyand et al. (1993).	800	71	29	Treadmill (AOD)
Spencer and Gastin (2001).	800	66	34	Treadmill (AOD)
Lacour et al. (1990).	800	59	41	Race $[La^-]_b$, assumed efficiency
Hill (1999).	800	58	42	Treadmill and race $[La^-]_b$

Table 2: Descriptive characteristics of subjects.

Event	N	Gender	Age (y)	Mass (kg)	Height (cm)	Peak $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)
400-m	11	M	21.8 (±4.0)	68.30 (±5.60)	178.0 (±3.0)	60.32 (±3.30)
800-m	9	M	19.8 (±3.5)	67.80 (±5.60)	179.6 (±6.4)	62.35 (±3.80)
400-m	5	F	20.8 (±4.8)	59.64 (±4.90)	172.8 (±4.8)	52.41 (±6.99)
800-m	2	F	18.0 (±1.4)	56.90 (±8.20)	169.0 (±1.4)	55.37 (±5.13)

Table 3: Mean (±SD) and range of values calculated by accumulated O_2 deficit (AOD) and La/PCr methods for the relative aerobic and anaerobic percentage energy contribution to both male (n= 11 and 9) and female (n=5 and 2) 400-m and 800-m races.

	AOD		La/PCr	
Event	**% aerobic**	**% anaerobic**	**% aerobic**	**% anaerobic**
400-m				
Male	**41.3** (±10.9)	**58.7** (±10.9)	**35.2** (±7.1)	**64.8** (±7.1)
	(31 - 60)	(40 – 69)	(26 – 45)	(55 – 74)
Female	**44.5** (±7.6)	**55.5** (±7.6)	**37.0** (±6.2)	**63.0** (±6.2)
	(31 – 52)	(48 – 69)	(30 – 45)	(54 – 70)
800-m				
Male	**60.3 *** (±9.0)	**39.7 *** (±9.0)	**63.4 *** (±5.2)	**36.6 *** (±5.2)
	(46 - 77)	(23 – 54)	(66 – 71)	(29 - 44)
Female	**70.1** (±16.2)	**29.9** (±16.2)	**68.6** (±3.6)	**31.4** (±3.6)
	(59 – 80)	(20 – 41)	(67 – 72)	(28 – 33)

Note: * denotes significantly different from 400-m ($p<0.05$) (no female analysis conducted).

Table 4: Mean (±SD) values for race time, peak race $\dot{V}O_2$, % peak $\dot{V}O_2$, peak race heart rate, % max heart rate, peak blood lactate, accumulated O_2 deficit (AOD), total energy cost and average speed for male (n=11 and 9) and female (n=5 and 2) 400-m and 800-m runs respectively.

	400-m Male	800-m Male	400-m Female	800-m Female
Race time (s)	52.2 (±1.9)	126.0 * (± 5.4)	60.2 (±4.1)	151.5 (±4.9)
Peak race $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	49.22 (±10.39)	55.81 (±7.96)	42.70 (±7.38)	50.26 (±6.33)
% peak $\dot{V}O_2$	81.6 (±8.1)	89.6 (±4.9)	81.6 (±3.2)	90.8 (±9.2)
Peak race HR (bpm)	187 (±7)	186 (±6)	193 (±8)	184 (±14)
% HR max	97 (±3)	96 (±3)	98 (±2)	96 (±4)
Peak $[La^-]_b$ ($mMol \cdot l^{-1}$)	13.9 (±2.3)	12.4 (±1.9)	13.3 (±2.9)	10.2 (±1.0)
Race AOD ($ml\ O_2\ eq \cdot kg^{-1}$)	48.0 (±14.8)	65.9 (±18.8)	41.8 (±10.5)	43.8 (±29.6)
Total Energy Cost ($ml\ O_2 \cdot kg^{-1} \cdot m^{-1}$)	0.205 (±0.027)	0.205 (±0.019)	0.186 (±0.022)	0.176 (±0.003)
Speed ($m \cdot s^{-1}$)	7.68 (±0.28)	6.27 * (±0.35)	6.64 (±0.51)	5.29 (±0.16)

Note: * denotes significantly different from male 400-m ($p<0.05$).

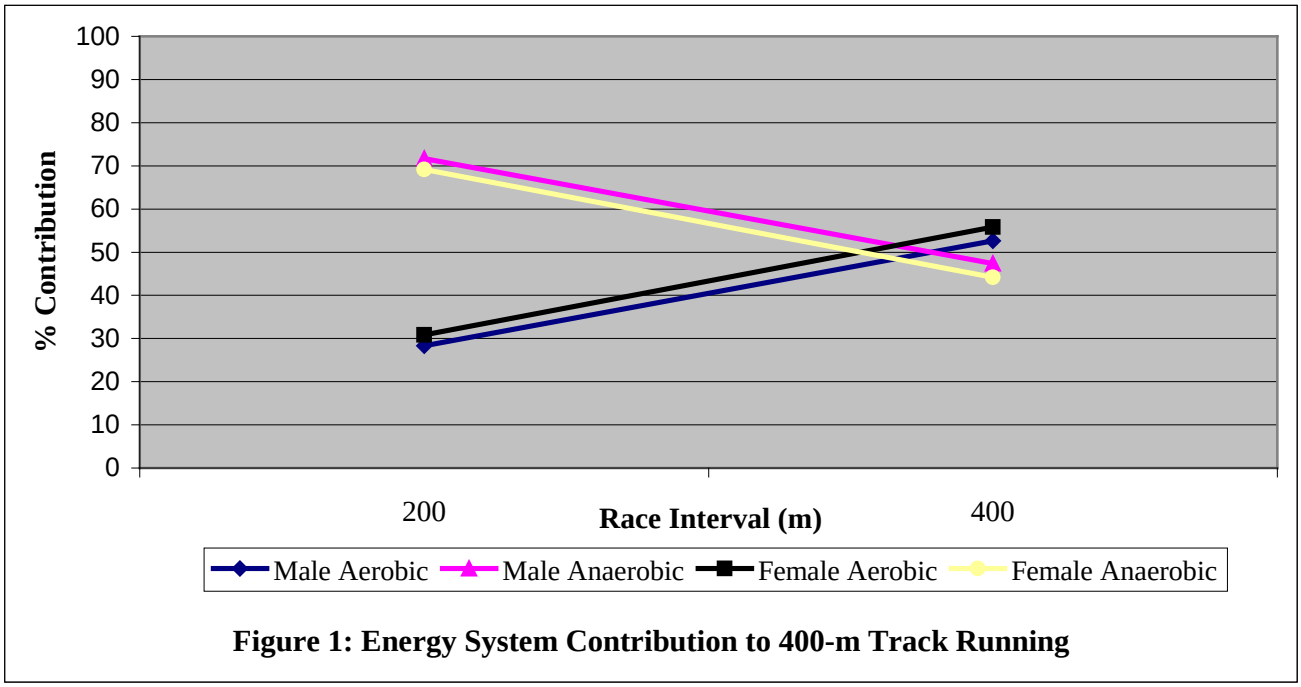

Figure 1: Energy System Contribution to 400-m Track Running

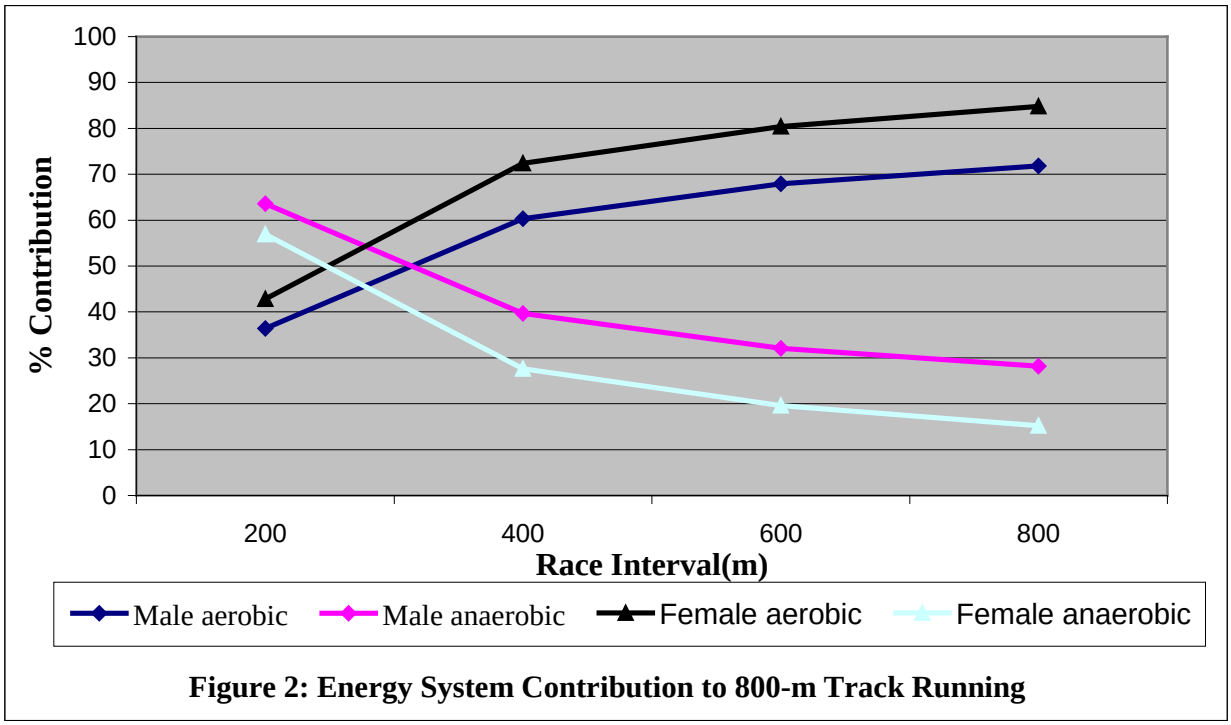

Figure 2: Energy System Contribution to 800-m Track Running