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Physiological Variables Related to 20 km Race Walk Performance

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Problem

Little is known regarding the physiological determinants of elite race walking performance as previous studies have considered heterogeneous groups (Hagberg and Coyle, 1983, male 20 km, $n = 8$; Reilly *et al.* 1979, male 20 km, $n = 9$; Dunster *et al.* 1993, female 10 km, $n = 12$; and Yoshida *et al.* 1989, female 5 km, $n = 8$ and 1990, female 5 km, $n = 5$). High level performance in the 20 km race walk events is sub ~1 hr 26 min for male and sub ~1 hr 40 min for female athletes. This level of performance equates to mean competition velocities of ~14.0 $km \cdot h^{-1}$ or faster and ~12.0 $km \cdot h^{-1}$ or faster for male and female athletes respectively (Castellini, 2005).

Aim

Therefore the purpose of this study was to examine the relationship between selected physiological variables identified during race walking exercise on a laboratory based motorised treadmill and 20 km competition performances of male and female race walkers from the UK Athletics Race Walking Squad.

Methodology

Seventeen male and twelve female athletes from the UK Athletics Race Walking Squad volunteered for this study, which had University ethical approval. Age (y), height (m), body mass (kg), body fat (%) and performance characteristics (race time, IAAF points and mean race speed) of the subjects are detailed in Tables 1 and 2.

The athletes completed between six and nine 4-minute stages of race walking on a motorised treadmill. All tests began at a 1% gradient, increasing by 0.5 $km \cdot h^{-1}$ each stage, with a starting speed 2.0 $km \cdot h^{-1}$ below the current race speed for 10 km of the subject. On completion of each stage a 20 µl arterialised capillary blood sample was obtained from the ear lobe for the determination of blood lactate (B_{lac}) values. Expired air was collected into a Douglas bag for the last 60 s of each stage to determine oxygen uptake (VO_2) and race walking economy (ml $O_2 \cdot kg^{-1} \cdot km^{-1}$). When heart rate (HR) exceeded 95 % of the predicted maximum or

B_{lac} exceeded 4 $mmol \cdot l^{-1}$ the treadmill gradient was increased by 1% every 60 s. The test continued until volitional exhaustion for the determination of maximum oxygen uptake (VO_{2max}).

The velocity at lactate turnpoint (v-LTP) was the race walking speed at which there was an abrupt and exponential increase in B_{lac} values (Jones, 2007). The velocity at VO_{2max} (v- VO_{2max}) was resolved by linear regression on sub-maximal race walking speed and VO_2values. Physiological data was compared with competition performance during a period of four weeks pre or post-test to minimise changes in aerobic conditioning (Jones and Doust (1997).

Table 1. Physical characteristics of the subjects . Anthropometric data was recorded in the laboratory prior to discontinuous incremental treadmill race walk test to volitional exhaustion.

		Age (y)	**Height (m)**	**Body mass (kg)**	**Body fat (%)**
♂	Mean ± SD	29 ± 8 (*n*=17)	1.78 ± 0.02 (*n*=17)	70.7 ± 6.8 (*n*=17)	12.0 ± 3.8 (*n*=16)
♀	Mean ± SD	29 ± 5 (*n*=12)	1.64 ± 0.08 (*n*=12)	54.3 ± 5.9 (*n*=12)	21.9 ± 2.5 (*n*=12)
♂♀	Mean ± SD	29 ± 7	1.72 ± 0.08	63.9 ± 10.4	16.3 ± 6.0

Table 2. Performance characteristics of the subjects . Race times (hh:mm:ss) convert to mean race speed ($km \cdot h^{-1}$). Performances correspond to point scores from the IAAF Scoring Tables (Szabo, 2003). Competition performance was only taken from a period of four weeks pre or post-test to minimise changes in aerobic conditioning (Jones and Doust (1997).

		20 km (hh:mm:ss)	**IAAF points**	**v-20 km ($km \cdot h^{-1}$)**
♂	Mean ± SD	01:31:13 ± 00:04:12 (*n*=17)	986 ± 75 (*n*=17)	13.2 ± 0.6 (*n*=17)
♀	Mean ± SD	01:48:32 ± 00:05:52 (*n*=12)	982 ± 60 (*n*=12)	11.1 ± 0.6 (*n*=12)
♂♀	Mean ± SD	01:38:23 ± 00:09:57	984 ± 68	12.3 ± 1.2

Outcomes

The physiological and descriptive data obtained during the discontinuous incremental treadmill race walk test to volitional exhaustion is displayed in Table 3. Results indicated that in athletes from the UK Athletics Race Walking Squad there were strong relationships between v-20 km and v-LTP and VO_{2max} in male athletes and between v-20 km and v-VO_{2max} in female athletes.

Table 3. Physiological and descriptive data obtained during discontinuous incremental treadmill race walk test to volitional exhaustion. The v-20 km is included for comparative purposes. Values in parenthesis are indicative of the number of subjects in which a particular variable was identified.

	v-20 km ($km \cdot h^{-1}$)	**VO_{2max} ($l \cdot min^{-1}$)**	**VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)**	**v-VO_{2max} ($km \cdot h^{-1}$)**	**LTP ($mmol \cdot l^{-1}$)**	**v-LTP ($km \cdot h^{-1}$)**	**VO_2 at LTP ($ml \cdot kg^{-1} \cdot min^{-1}$)**	**Fraction of VO_{2max} at LTP (%)**	**Race walking economy ($ml\ O_2 \cdot kg^{-1} \cdot km^{-1}$ at 12 $km \cdot h^{-1}$)**
♂ Mean	13.2	5.0	70.1	14.8	2.8	13.4	62.0	87	258.1
± SD	0.6	0.5	8.2	1.0	0.9	0.8	6.2	6	24.3
	(*n*=17)	(*n*=16)	(*n*=16)	(*n*=17)	(*n*=17)	(*n*=17)	(*n*=14)	(*n*=13)	(*n*=15)
♀ Mean	11.1	3.1	56.7	12.9	2.9	11.8	50.6	89	257.8
± SD	0.6	0.6	7.3	0.7	1.3	0.5	8.9	8	44.9
	(*n*=12)	(*n*=12)	(*n*=12)	(*n*=12)	(*n*=12)	(*n*=12)	(*n*=12)	(*n*=12)	(*n*=11)
♂♀ Mean	12.3	4.2	64.8	14.0	3.0	12.8	57.3	89	258.0
± SD	1.2	1.1	10.5	1.3	1.1	1.0	9.4	7	33.7

Analysis of variance and correlations between variables

The velocity during a 20 km race (v-20 km) for male and female athletes was significantly different from v-LTP and v-VO_{2max} ($p < 0.05$). In male athletes velocity at lactate turnpoint (v-LTP) had the strongest correlation with v-20 km ($r = 0.740$, $p < 0.05$, Table 4a). In female athletes velocity at VO_{2max} (v-VO_{2max}) had the strongest correlation with v-20 km ($r = 0.789$, $p < 0.05$, Table 4b). Based on the outcome of the present study the results suggested that the most important variables to examine when investigating variance in race walking performance were v-LTP and v- VO_{2max}.

Explanations of variance in performance

The adjusted R^2 value derived from multiple stepwise linear regression in Table 5a indicated that 53 % of the variance in male v-20 km was explained by variance in v-LTP and the addition of the variance in VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) to the variance in v-LTP explained 71 % of the variance. The other statistically significant correlates with v-20 km (v-VO_{2max}, $r = 0.690$, $p < 0.05$; VO_2 at LTP, $r = 0.578$, $p < 0.05$) did not add to the regression and were excluded by the stepwise model. In female athletes the adjusted R^2 value indicated that 59 % of the variance in female v-20 km was explained by variance in v-VO_{2max} (Table 5b). The other statistically significant correlate with v-20 km (v-LTP, $r = 0.620$, $p < 0.05$) did not add to the regression and was excluded by the stepwise model.

The multiple stepwise linear regression models gave different explanations of variance in 20 km performance between male and female athletes, i.e. the submaximal variables v-LTP in males and v-VO_{2max} in females. However v-LTP and v-VO_{2max} did both correlate with v-20 km: v-VO_{2max} with v-20 km in males (r = 0.690, p <0.05); and v-LTP with v-20 km in females (r = 0.620, p <0.05). The truncated product method (TPM) was used in the analysis of the 20 km race walk events. When combining p values for Pearson's product moment correlation coefficients v-LTP, VO_{2max} and v-VO_{2max} TPM gave p <0.01 for both male and female athletes, indicating all statistically significant results in the data set added to the level of significance and were not due to chance. Analysis of covariance identified that gender did not make a significant contribution to regression equations of the independent variables in the male and female groups. Therefore a common regression line was drawn to estimate the linear relationship between v-20 km and the independent variables presented as male and female subject group scatter plots in Figures 1 to 3.

Table 4a. Correlation coefficients (r) for male 20 km athletes and descriptive data obtained during discontinuous incremental treadmill race walk test to volitional exhaustion. * = p <0.05.

Male athletes	**VO_{2max} (ml·kg^{-1}·min^{-1})**	**v-VO_{2max} (km·h^{-1})**	**LTP (mmol·l^{-1})**	**v-LTP (km·h^{-1})**	**VO_2 at LTP (ml·kg^{-1}·min^{-1})**	**Fraction of VO_{2max} at LTP (%)**	**Race walking economy (ml O_2·kg^{-1}·km^{-1} at 12 km·h^{-1})**
v-20 km (km.h^{-1})	0.64* (*n*=16)	0.69* (*n*=17)	-0.39 (*n*=17)	0.74* (*n*=17)	0.59* (*n*=15)	-0.35 (*n*=14)	-0.12 (*n*=15)
VO_{2max} (ml·kg^{-1}·min^{-1})		0.47 (*n*=16)	0.10 (*n*=16)	0.29 (*n*=16)	0.82* (*n*=14)	-0.57 (*n*=14)	0.51 (*n*=15)
v-VO_{2max} (km·h^{-1})			-0.42 (*n*=17)	0.84* (*n*=17)	0.20 (*n*=15)	-0.53 (*n*=14)	-0.36 (*n*=15)
LTP (mmol·l^{-1})				-0.35 (*n*=17)	0.33 (*n*=15)	-0.22 (*n*=14)	0.41 (*n*=15)
v-LTP (km·h^{-1})					0.24 (*n*=15)	-0.16 (*n*=14)	-0.46 (*n*=15)
VO_2 at LTP (ml·kg^{-1}·min^{-1})						-0.01 (*n*=14)	0.58* (*n*=14)
F VO_{2max} at LTP (%)							-0.12 (*n*=14)

Table 4b. Correlation coefficients (*r*) for female 20 km athletes and descriptive data obtained during discontinuous incremental treadmill race walk test to volitional exhaustion. * = p <0.05.

Female athletes	**VO_{2max} (ml·kg^{-1}·min^{-1})**	**v-VO_{2max} (km·h^{-1})**	**LTP (mmol·l^{-1})**	**v-LTP (km·h^{-1})**	**VO_2 at LTP (ml·kg^{-1}·min^{-1})**	**Fraction of VO_{2max} at LTP (%)**	**Race walking economy (ml O_2·kg^{-1}·km^{-1} at 12 km·h^{-1})**
v-20 km (km·h^{-1})	0.39 (n=12)	0.79* (n=12)	-0.32 (n=12)	0.62* (n=12)	-0.15 (n=12)	-0.29 (n=12)	-0.04 (n=11)
VO_{2max} (ml·kg^{-1}·min^{-1})		0.11 (n=12)	0.09 (n=12)	-0.00 (n=12)	0.27 (n=12)	0.17 (n=12)	0.78* (n=11)
v-VO_{2max} (km·h^{-1})			-0.38 (n=12)	0.72* (n=12)	-0.34 (n=12)	-0.45 (n=12)	-0.36 (n=11)
LTP (mmol·l^{-1})				-0.21 (n=12)	0.59* (n=12)	0.58 (n=12)	0.19 (n=11)
v-LTP (km·h^{-1})					0.028 (n=12)	0.14 (n=12)	-0.24 (n=11)
VO_2 at LTP (ml·kg^{-1}·min^{-1})						0.83* (n=12)	0.57 (n=11)
F VO_{2max} at LTP (%)							0.53 (n=11)

Table 5a. The adjusted R^2 value indicates that 62 % of the variance in male v-20 km was explained by variance in v-LTP (model 1) and the addition of the variance in VO_{2max} to the variance in v-LTP explained 74 % of the variance (model 2).

20 km race walk Male athletes			**Multiple stepwise linear regression**		
Model number	**Variables**	**Correlation coefficient (*r*)**	**Multiple r^2**	**R^2**	**Adjusted R^2**
1	v-LTP (km·h^{-1})	0.74	0.74	0.56	0.53
2	v-LTP (km·h^{-1}) & VO_{2max} (ml·kg^{-1}·min^{-1})	0.64	0.87	0.75	0.71

Table 5b The adjusted R^2 value indicates that 59 % of the variance in female v-20 km was explained by variance in v-VO_{2max}.

20 km race walk Female athletes		**Multiple stepwise linear regression**		
Variables	**Correlation coefficient (*r*)**	**Multiple r^2**	**R^2**	**Adjusted R^2**
v-VO_{2max} (km·h^{-1})	0.79	0.79	0.62	0.59

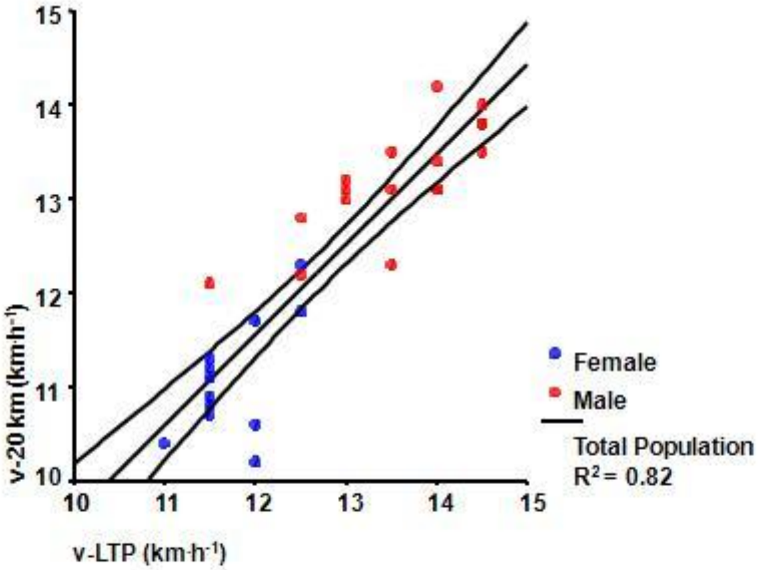

Figure 1. The relationship between 20 km performance speed and the velocity at lactate turnpoint (v-LTP) in male and female athletes with the linear relationship estimated by the common regression line fitted to the data. The lines fitted above and below show the 95 % confidence intervals of the mean relationship between the variables.

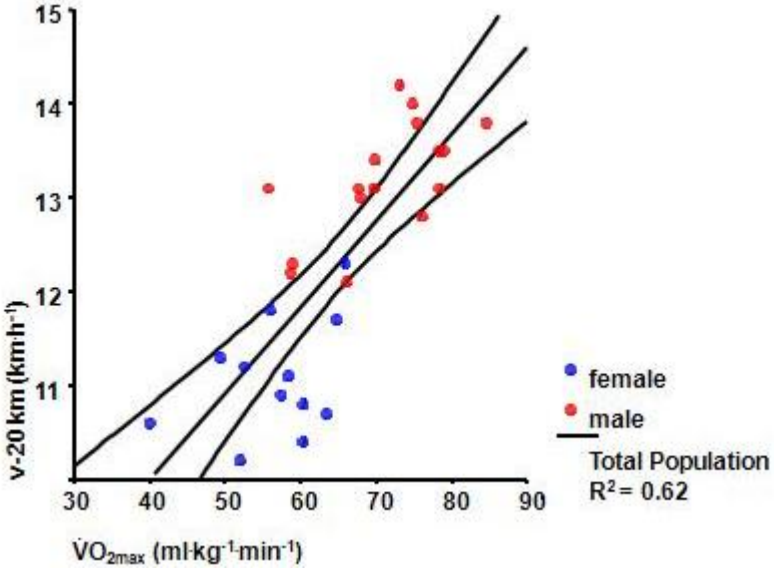

Figure 2. The relationship between 20 km performance speed and VO_{2max} in male and female athletes with the linear relationship estimated by the common regression line fitted to the data. The lines fitted above and below show the 95 % confidence intervals of the mean relationship between the variables.

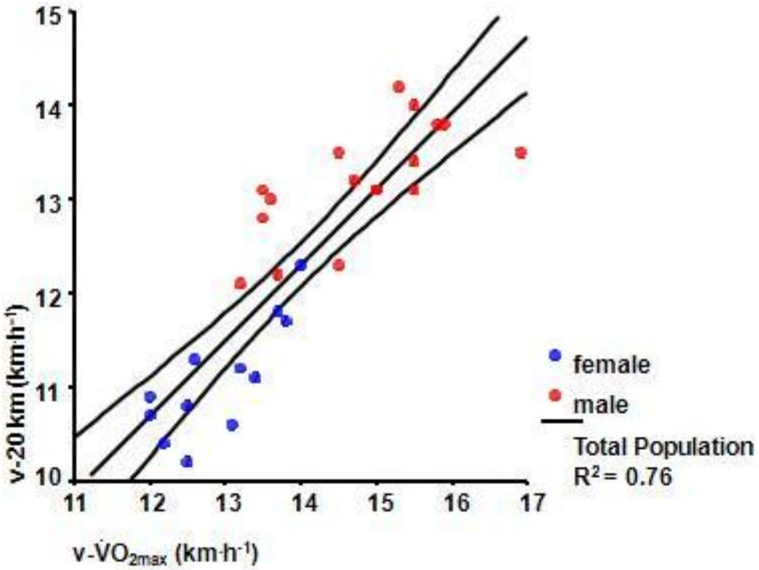

Figure 3. The relationship between 20 km performance speed and the velocity at VO_{2max} (v-VO_{2max}) in male and female athletes with the linear relationship estimated by the common regression line fitted to the data. The lines fitted above and below show the 95 % confidence intervals of the mean relationship between the variables.

Discussion

Maximum oxygen uptake

The male athletes' mean VO_{2max} values (70.1 ± 8.2 ml·kg^{-1}·min^{-1}, *n* = 17) were similar to those reported by Reilly *et al.* (1979) (70.0 ± 3.0 ml·kg^{-1}·min^{-1}, *n* = 9), Brisswalter *et al.* (1998) (70.6 ± 4.1 ml·kg^{-1}·min^{-1}, *n* = 9), Franklin *et al.* (1981) (62.9 ± 4.1 ml·kg^{-1}·min^{-1}, *n* = 9) and Hagberg and Coyle (1984) (58.1 ± 1.5 ml·kg^{-1}·min^{-1}, *n* = 8). The female athletes mean VO_{2max} of 55.7 ± 8.6 ml·kg^{-1}·min^{-1} is similar to the values reported by Dunster *et al.* (1993) (57.3 ± 7.7 ml·kg^{-1}·min^{-1}, *n* = 12) and Yoshida *et al.* (1989 and 1990) (49.8 ± 2.5 ml·kg^{-1}·min^{-1}, *n* = 8 and 49.9 ± 3.0 ml·kg^{-1}·min^{-1}, *n* = 5). So the athletes taking part in the present studies attained a similar profile in terms of VO_{2max} as other elite level race walkers.

20 km performance did correlate with VO_{2max} in male ($r = 0.64$, $p < 0.05$, $n = 31$) but not female athletes ($r = 0.39$, $p > 0.05$, $n = 12$). These results showed some contradictions with previous researchers, e.g. VO_{2max} did not correlate with 20 km race walk performance in the male athletes studied by Hagberg and Coyle (1983) ($r = 0.62$, $p > 0.05$, $n = 8$) or Reilly *et al.* (1979) ($r = 0.53$, $p > 0.05$, $n = 9$) but Yoshida *et al.* (1989) found a significant correlation between VO_{2max} and female 5 km walk performance ($r = 0.74$, $p < 0.05$, $n = 8$). This may reflect the lower subject numbers in the studies by these authors or the relative homogeneity of the subject group in the present study, i.e. the more homogenous the group, the less likely statistical significance as demonstrated in literature relating marathon running performance to VO_{2max} (Maughan and Leiper, 1983; Sjödin & Svedenhag, 1985). Moreover, the mean 20 km performance of the male athletes

studied by Hagberg and Coyle (1983) was 1 h 52 min ± 6 min, which was much slower than the 1 h 31 min ± 4 min of the male athletes in the present study.

Although VO_{2max} did not correlate with female race walking performance v- VO_{2max} explained a large segment of variance among the female athletes 20 km race pace: 59 % by variance in v- VO_{2max} when entered into the stepwise multiple linear regression analysis (Table 5b). In a study of 5 km cross country running performance peak exercise treadmill grade at the termination of a running test to volitional exhaustion was the strongest correlate among physiological variables examined by Berg *et al.* (1995), which is a similar method to that used to determine v-VO_{2max} in the present study. The VO_{2max} values recorded by the female subjects (56.7 ± 7.3 $ml \cdot kg^{-1} \cdot min^{-1}$, $n = 12$), like the male athletes, were similar to those reported for other high level female race walkers and endurance athletes.

Blood lactate variables

The variables related to B_{lac} were closely correlated with the male athletes v-20 km in particular v-LTP (20 km study, $r = 0.74$, $p < 0.05$, $n = 17$). These results are in agreement with the literature relating to distance running ($r = 0.97$, $p < 0.05$, $n = 18$, 15 km race, Farrell *et al.* 1979) and race walk performance specifically by Hagberg and Coyle (1983) ($r = 0.95$, $p < 0.05$, $n = 8$, 20 km race walk). The correlations between velocity at LTP and male athlete performance suggests that success in race walk competition over 20 km can be largely related to the ability to attain and sustain a high race walking speed without accumulation of B_{lac}, i.e. the energy contribution to ATP resynthesis is largely aerobic.

Blood lactate variables were also closely correlated with the female athletes v-20 km, in particular v-LTP ($r = 0.62$, $p < 0.05$, $n = 12$). These results were in agreement with the literature relating to female 5 km cross country running performance by Berg *et al.* (1995) ($r = 0.83$, $p < 0.05$, $n = 7$, female 5 km cross country run) and female race walk competition performance by Yoshida *et al.* (1989) ($r = 0.85$, $p < 0.05$, $n = 8$, 5 km walk). Like the correlation between v-LTP in the male athletes, the female data suggested that success in 20 km race walk competitions could be largely related to the ability to attain and sustain a high race walking speed without accumulation of B_{lac}.

Aerobic energy contribution to the 20 race walk events

The average energy cost of the 20 km and performances by the male athletes in the present study according to Equation 1 by Arcelli (1996) was 51.6 ml $O_2 \cdot kg^{-1} \cdot min^{-1}$.

Equation 1. "race walking"

$(6.86v - 38.8)$ = average energy cost (ml $O_2 \cdot kg^{-1} \cdot min^{-1}$)

where v = velocity in $km \cdot h^{-1}$

The variables entered into the stepwise multiple linear regression analysis have been identified as central to performance speed in endurance athletes, including race walkers (Coyle, 1995; and Bassett and Howley, 2000). V-LTP explained a large segment of variance in race pace among the male athletes (53 %, Table 5a) and correlated with performance in female 20 km ($r = 0.62$, $p < 0.05$). In the present studies LTP was about 3.0 mmol·l^{-1} (2.8 ± 0.9 mmol·l^{-1}, male athletes and 2.9 ± 1.3 mmol·l^{-1}, female athletes, Table 3), which may exemplify the uneven aerobic condition described by Antonutto and di Prampero (1995) in which lactate production and removal were equally increased demonstrating how whole body sources for muscular work could be entirely aerobic under steady state conditions despite a higher than resting B_{lac} level. They noted that peak glycogen oxidation rates are attained at the "uneven aerobic" exercise intensity, which occurred at LTP. Therefore the uneven aerobic condition may set not only the intensity of exercise, but also the capacity, as it may be responsible for an increased glycogen flux in the muscle fibres producing lactate (Antonutto and Di Prampero, 1995). The accumulation of B_{lac} can be attributed to either increased formation or decreased removal of lactate in the muscle, so at high exercise intensities demand for carbohydrate may result in an increased hydrogen concentration in the muscle, which could have a negative impact on muscle function. Thus, there would be a rapid carbohydrate turnover and increasing acidosis in the muscle above exercise intensities associated with LTP, which would be inconsistent with being able to maintain a faster pace over the race distance (Bassett and Howley, 2000). The uneven aerobic condition may also be a demonstration of the lactate shuttle (Brooks, 1988) where lactate produced by active type II fibres could have reached muscle capillaries, proceeding into the general circulation, thus elevating B_{lac}, or may have reached adjacent type I fibres to be oxidised, i.e. supporting the findings of Donovan *et al.* (2000) where approximately 50 % of lactate removal in skeletal muscle could be accounted for by oxidation in type I and IIa fibres.

Fractional utilisation of VO_{2max} at LTP was about 88 % in the study (88 ± 4 % mmol·l^{-1}, male athletes and 89 ± 8 % mmol·l^{-1}, female athletes, Table 3) with the corresponding B_{lac} values of about 3.0 mmol·l^{-1}, possibly resulting from the combination of active muscle mass and the intensity of the muscle activation that was proposed by Billat (2003) to be factors in the appearance of lactate in the blood. Accordingly LTP in the race walkers in the present studies could have been affected by muscle fibre type, lactate transport across membranes (possibly involving MCT proteins in cell membranes (Brooks, 2000)), blood flow and blood distribution (Billat, 2003).

The relationship between LTP and muscle fibre type was studied by Ivy *et al.* (1980) who found a correlation of $r = 0.74$ ($p < 0.05$, $n = 9$ male) between LTP and percentage of type I muscle fibres during cycle ergometer exercise. Race walking above LTP would result in a different metabolic response compared with race walking at or below LTP, i.e. a higher rate of energy utilisation and increased levels of B_{lac}. Holloszy and Coyle (1984) found the rate of energy utilisation, where B_{lac} began to accumulate, was limited by skeletal muscle oxidative capacity and strongly influenced by training. Therefore it could be of value to investigate the influence of training on LTP in race walkers as this variable was the strongest correlate with performance in male athletes; and was correlated with female performance.

Two physiological variables combine in v-LTP according to Coyle (1995): the race walk VO_2 at LTP and the race walk speed that could be achieved at that VO_2, described as submaximal economy. The VO_2at LTP for an event such as the 20 km race walk was shown to be closely related to the VO_2 that an athlete could sustain over the given duration of an event by Coyle (1995) and was described as a combination of VO_{2max} and the fraction of VO_{2max} that could be maintained during performance, e.g. 20 km race walk. Bassett and Howley (2000) noted fractional utilisation of VO_{2max} was linked to changes in muscle oxidative capacity arising from chronic training stimulus as found by Holloszoy and Coyle (1984).

Race walking economy

There was no correlation between race walking economy (ml $O_2 \cdot kg^{-1} \cdot km^{-1}$ at 12 $km \cdot h^{-1}$) and performance in the study (male athletes, $r = -0.12$, $p > 0.05$, $n = 15$, female athletes, $r = -0.04$, $p > 0.05$, $n = 11$), which is in agreement with Yoshida *et al.* (1989), although these authors examined a different racing distance: 5 km. However Hagberg and Coyle (1983) did report that race walking economy in male athletes was significantly related to 20 km race pace ($r = -0.89$, $p < 0.05$, $n = 8$, economy identified by VO_2 values at 10 $km \cdot h^{-1}$) and concluded that submaximal economy appeared to be related more closely to performance in race walking than in running. In runners with a similar VO_{2max} running economy is a good predictor of performance (Saunders *et al.* 2004) so the lack of correlation between race walking economy and performance (i.e. v-20 km) may reflect a heterogeneous athlete population in the present studies, contradicting the comment above about homogeneity and VO_{2max}.

The correlation between performance and VO_2 at LTP in the study was not uniform (male athletes, $r = 0.69$, $p < 0.05$, $n = 15$, female athletes, $r = -0.15$, $p > 0.05$, $n = 12$), e.g. only the correlation for the male athletes in the 20 km study was in agreement with the findings of Hagberg and Coyle (1983) who also reported a correlation in male 20 km athletes ($r = 0.82$, $p < 0.01$, $n = 8$), while Yoshida *et al.* (1989) found no correlation between race walking economy and v-5 km in female race walkers. Hagberg and Coyle (1983) noted that the VO_2 at LTP and the submaximal economy appeared to contribute to a different extent in the determination of v-LTP during running and race walking exercise modes, i.e. submaximal economy appeared to be more closely related to race walking performance than running performance, proposing that this was related to race walk biomechanics rather than energy metabolism. In the present study the fastest (athlete *a*) and fourth fastest (athlete *b*) male 20 km athletes were identical in their VO_2 at LTP (68.6 $ml \cdot kg^{-1} \cdot min^{-1}$), yet athlete *a* was walking 3.6 % faster in the race (20 km = 1 h 25 min 56 s v 1 h 28 min 34 s). Hagberg and Coyle (1983) found a difference of 0.6 $ml \cdot kg^{-1} \cdot min^{-1}$ between VO_2 at LTP in three male athletes but a variation in performance of 11 % and concluded the differences in v-20 km were not due to differing abilities to expend energy below LTP, but in submaximal economy, i.e. race walk speed at a given VO_2. The difference in v-20 km between athlete *a* and athlete *b* and the probable impact of submaximal (or race walking) economy is shown in Figure 4.

The fraction of VO_{2max} at LTP was 88 ± 4 % in the male athletes, which compares with trained marathon runners reported to utilise 94% of VO_{2max} over 5 km and 82% over 42.2 km (Davies and Thompson, 1979) and between 80 and 85 % (Bassett and Howley, 2000) and 86 % over 42.2 km (Sjödin and Svedenhag, 1985). The 20 km is not walked at 100 % VO_{2max}, however ATP production is dependant on the VO_2 that can be maintained during the race. In the present studies this would be determined by the VO_{2max} and the fraction of VO_{2max} that the athlete could achieve. Arcelli (1996) calculated that to complete 20 km in World Record time (1 h 17 min 21 s) the athlete would have to maintain a VO_2 of 68.1 $ml \cdot kg^{-1} \cdot min^{-1}$ throughout the race. As a result, should it be possible to walk 20 km at 100 % VO_{2max} the athlete would require a VO_{2max} of 68.1 $ml \cdot kg^{-1} \cdot min^{-1}$ to race the distance in 1 h 17 min 21 s. In the present study v-LTP (13.5 ± 0.9 $km \cdot h^{-1}$) was slightly higher than v-20 km (13.2 ± 0.6 $km \cdot h^{-1}$), however the fraction of VO_{2max} at LTP (88 ± 4 %) suggests a VO_{2max} in the region of 77.0 - 82.0 $ml \cdot kg^{-1} \cdot min^{-1}$ would be required to race walk 20 km in World Record time.

The examination of fractional utilisation demonstrates how VO_{2max} establishes the upper limit for performance in the 20 km race walk but does not resolve the outcome of competition (Figure 5), e.g. the highest VO_{2max} value recorded in the study was 79.0 $ml \cdot kg^{-1} \cdot min^{-1}$ by an athlete who recorded 1 h 28 min 34 s in the 4 week time frame either side of his laboratory visit, compared to 73.1 $ml \cdot kg^{-1} \cdot min^{-1}$ recorded by the fastest 20 km athlete in the study whose time was 1 h 24 min 43 s. In the study the fraction of VO_{2max} at LTP did not correlate with v-20 km (r = -0.35, $p > 0.05$, Table 4a), which is in agreement with studies of experienced athletes who have prepared for marathon races with appropriate endurance training (Sjödin and Svedenhag, 1985). If the present study had included club level and recreational athletes to provide a larger variation in 20 km performance then fractional utilisation of VO_{2max} may have provided a statistically significant correlation with v-20 km. In a study of male cyclists and triathletes (n =36) Meyer *et al.* (1999) found a large variation between the fraction of VO_{2max} and exercise intensities defined in relation to LTP. This led them to conclude that the percentage of VO_{2max} was not suitable for determining exercise intensities alone and that B_{lac} measurements were preferable, e.g. in the present study the correlations between v-20 km and fractional utilisation of VO_{2max} at LTP and v-LTP were r = -0.35, $p > 0.05$ and r = 0.74, $p < 0.05$ respectively (Table 4a).

The fraction of VO_{2max} at LTP was 89 ± 8 % for the female athletes in the study and did not correlate with v-20 km (r = -0.29, $p > 0.05$, Table 4b) or with VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) ($r$ = 0.17, $p > 0.05$, Table 3.5b), which is similar to the findings of Rusko *et al.* (1980) who found no correlation between fraction of VO_{2max} at LTP or VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) in female cross country skiers (n = 15). Rusko *et al.* (1986)

found statistically significant correlations between VO_2 at LTP and citrate synthase ($r = 0.58$, $p < 0.05$, $n = 15$) and fraction of VO_{2max} at LTP and succinate dehydrogenase ($r = 0.63$, $p < 0.05$, $n = 15$) from muscle biopsy samples taken from the vastus lateralis muscle, which led them to conclude that LTP seemed to be related to the oxidative capacity of muscle. Therefore in an investigation into the influence of training on LTP in race walkers an improvement in LTP may be explained by improvements in the oxidative capacity of the skeletal muscle.

Race walking economy, expressed as the energy required per unit of mass to race walk over a horizontal distance at 12.0 $km \cdot h^{-1}$ (ml $O_2 \cdot kg^{-1} \cdot km^{-1}$) did not correlate with v-20 km. However it is difficult to discount race walking economy as it may have contributed to the differences in v-20 km between athlete *a* and *b* who were identical in VO_2at LTP (Figure 4). Likewise race walking economy may have interacted with VO_{2max} to explain the differences in v-VO_{2max} between athlete *d* and *e* who were identical in VO_{2max} (Figure 6). This is similar to Daniels (1992) findings that different running economies resulted in a different v-VO_{2max} in distance runners of equal VO_{2max}. Each athlete exhibits a linear relationship between race walking speed and VO_2, which interact to give v-VO_{2max}. As Figure 6 showed there was variation between each pair of athletes in how much oxygen it cost to race walk at given speeds, i.e. athlete *e* had the better race walking economy respectively resulting in the faster v-VO_{2max}. Differences between v-VO_{2max} in athletes with virtually identical race walking economy may explain the differences in VO_{2max} between athlete *e* and *f* (Figure 7), which also supports the findings of Daniels (1992) in his study of running economy. Moreover, Yoshida *et al.* (1990) found race walking economy improved 8.8 % from 43.5 ± 3.1 to 40.0 ± 2.4 $ml \cdot kg^{-1} \cdot min^{-1}$ at 10.2 $km \cdot h^{-1}$ ($p < 0.05$, $n = 5$) following an eight week training intervention in competitive female race walkers resulting in a 6.8 % improvement in 5 km walk performance ($p > 0.05$). The authors drew a similar conclusion to Hagberg and Coyle (1983) that exercise economy was possibly a specific phenomenon for competitive race walkers compared to runners, alluding to race walking technique having a greater impact on variance in race walking performance than running technique on variance in running performance?

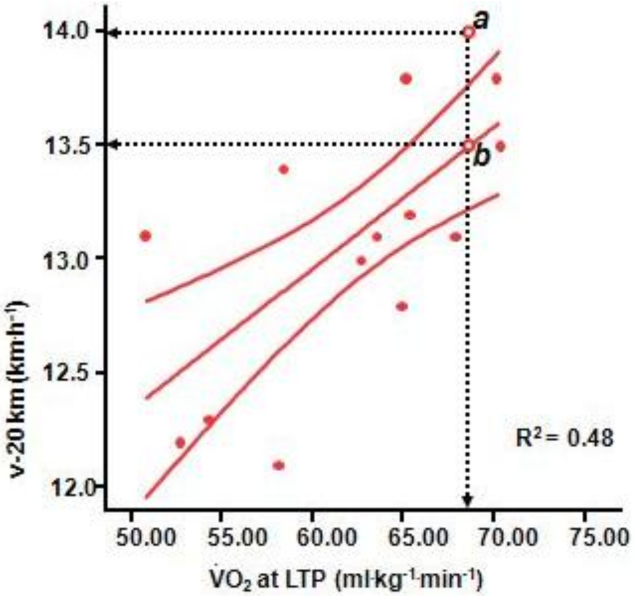

Figure 4. Athletes *a* and *b* have identical VO_2 at LTP (68.6 ml·kg^{-1}·min^{-1}). The v-20 km of athlete *a* was 14.0 km·h^{-1} v 13.5 km·h^{-1} for athlete *b*. The ability to expend energy before LTP is identical, therefore differences in v-20 km maybe explained by submaximal economy, i.e. race walk speed at a given VO_2.

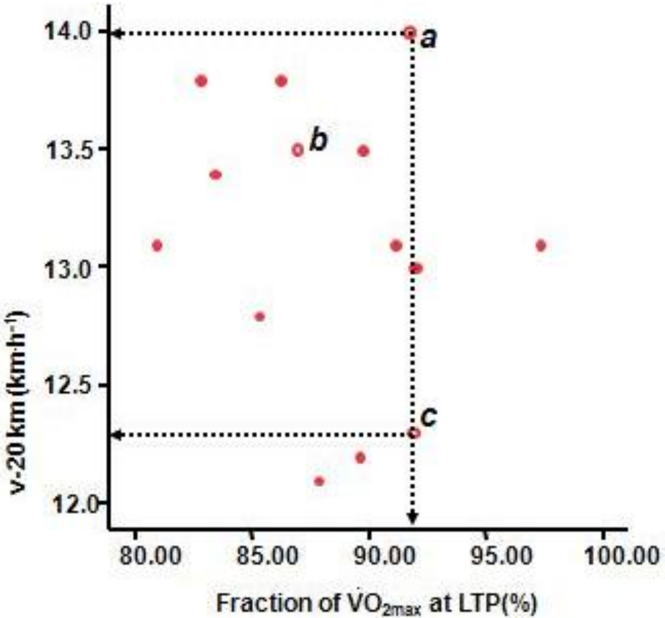

Figure 5. Athletes *a* and *c* have identical fractional utilisation of VO_{2max}. The v-20 km of athlete *a* was 14.0 km·h^{-1} v 12.3 km·h^{-1} for athlete *c*. The examination of fractional utilisation demonstrates how VO_{2max} establishes the upper limit for performance in the 20 km race walk but does not resolve the outcome of competition. NB athlete *b* from Figure 4 is included for comparative purposes.

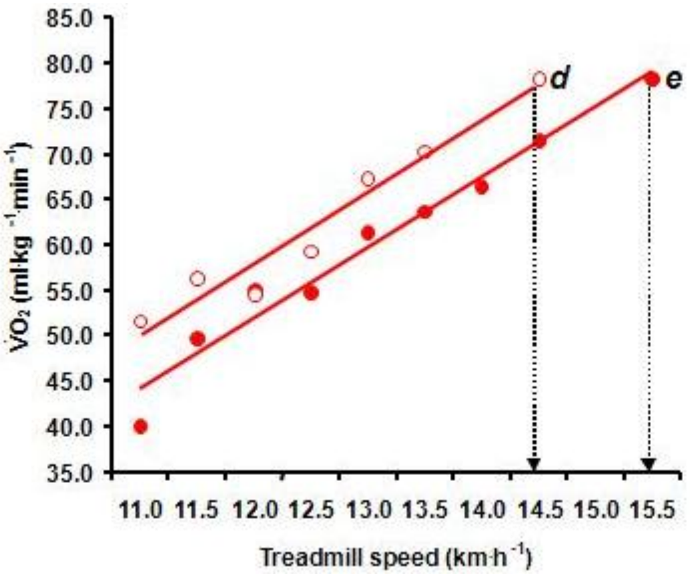

Figure 6. Athletes *d* and *e* have identical VO_{2max}. The v-VO_{2max} of athlete *d* was 14.5 km·h^{-1} v 15.5 km·h^{-1} for athlete *e*. A line was drawn through the VO_2 data points to create a race walking economy line ending at the VO_{2max} of each athlete. A perpendicular line was dropped from the VO_{2max} value of each athlete to the x-axis to demonstrate the v-$VO_{2max.}$ The data points used to construct the race walking economy lines for athletes *d* and *e* are lower at every point but there is a clear 1 km·h^{-1} difference in v-VO_{2max} between the two, i.e. athlete *e* is more economical than athlete *d*.

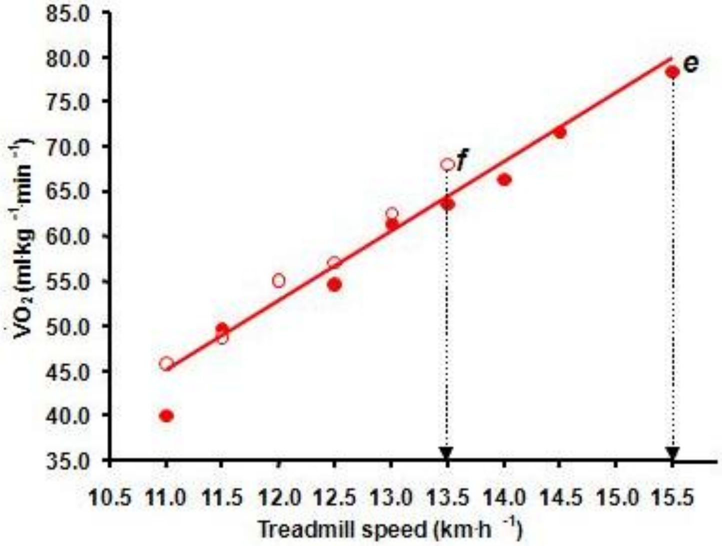

Figure 7. Athletes *e* and *f* have identical race walking economy. The v-VO_{2max} of athlete *f* was 13.5 km·h^{-1} v 15.5 km·h^{-1} for athlete *e*. A line was drawn through the VO_2 data points to create a common race walking economy line. A perpendicular line was dropped from the VO_{2max} value of each athlete to the x-axis to demonstrate the v-$VO_{2max.}$ The Figure demonstrates the influence of VO_{2max} on v-VO_{2max} in two athletes with virtually identical race walking economy.

Despite the lack of correlation between race walking economy and v-20 km in the present study, the examination of VO_2 at LTP, fractional utilisation of VO_{2max} and differences in v-VO_{2max} demonstrated the apparent impact of race walking economy in explaining some of the variation in v-20 km. The interrelationships between these variables are summarised in Figure 8.

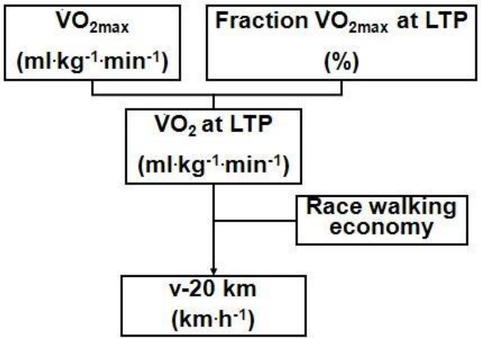

Figure 8. The relationships between VO_{2max}, the fraction of VO_{2max} at LTP, the VO_2 at LTP, race walking economy and (e.g.) v-20 km (adapted from Bassett and Howley, 1999).

Conclusions

Correlations of descriptive data obtained during the discontinuous incremental treadmill race walk test to volitional exhaustion and v-20 km showed that among the variables analysed only v-LTP and v-VO_{2max} had statistically significant correlations (p <0.05) in both male and female data analysis. VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) was only significantly correlated (p <0.05) with v-20 km in male athletes, however v-VO_{2max} is strongly affected by race walking economy and VO_{2max} (Bassett and Howley, 1999; Coyle, 1995; Daniels and Daniels, 1992; Morgan *et al.* 1989) so it may be unwise to dismiss the importance of VO_{2max} in the other athletes. VO_{2max} has been found to increase by about 20 % in athletes following endurance training, highlighting the large genetic component to this measure (Bouchard *et al.* 1999), whereas muscle oxidative capacity has been found to increase by between 40 and 100 % (Holloszoy and Coyle, 1984) suggesting variables such as v-LTP are trainable, as is v-VO_{2max} (Daniels, 1992; Billat *et al.* 1999), largely via its economy component. The efficacy of investigating the training response in v-LTP and v-VO_{2max} to race walking training is worthy of research; moreover the role of race walking biomechanics in variance in race walking economy warrants investigation despite no correlations between race walking performance and economy *per se* in the present studies.

Summary

This study provides new data on an athletics event group that has received scant attention in the academic literature. In highly trained male and female athletes competing in the 20 km race walk event velocity at lactate turnpoint and velocity at maximum oxygen uptake correlate with performance. Relationships between physiological variables and performance may be indicative of the intensities at which the race distance is performed. Moreover differences in race walking economy may discriminate between performers exhibiting similarities in other physiological variables.

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