Effects of dominant somatotype on aerobic capacity trainability

M Chaouachi, A Chaouachi, K Chamari, M Chtara, Y Feki, M Amri, F Trudeau

Purpose: This study examined the association between dominant somatotype and the effect on aerobic capacity variables of individualised aerobic interval training.

Methods: Forty one white North African subjects (age 21.4 ± 1.3 years; $V_{\text{O}2\text{max}} = 52.8 ± 5.7$ ml kg$^{-1}$ min$^{-1}$) performed three exercise tests 1 week apart (i) an incremental test on a cycle ergometer to determine $V_{O2\text{max}}$ and $V_{O2}$ at the second ventilatory threshold (VT2); (ii) a VAM-EVAL test to determine maximal aerobic speed ($V_{O2\text{max}}$); and (iii) an exhaustive constant velocity test to determine time limit performed at 100% of $V_{O2\text{max}}$ (tlim100). Subjects were divided into four somatometric groups: endomorphs-mesomorphs (Endo-meso; n = 9), mesomorphs (Meso; n = 11), mesomorphs-ectomorphs (Meso-ecto; n = 12), and ectomorphs (Ecto; n = 9). Subjects followed a 12 week training program (two sessions/week). Each endurance training session consisted of the maximal number of successive fractions for each subject. Each fraction consisted of one period of exercise at 100% of $V_{O2\text{max}}$ and one of active recovery at 60% of $V_{O2\text{max}}$. The duration of each period was equal to half the individual tlim100 duration (153.6 ± 39.7 s). After the training program, all subjects were re-evaluated for comparison with pre-test results.

Results: Pre- and post-training data were grouped by dominant somatotype. Two way ANOVA revealed significant somatotype-aerobic training interaction effects ($p<0.001$) for improvements in $V_{O2\text{max}}$, $V_{O2\text{max}}$ expressed classically and according to allometric scaling, and $V_{O2}$ at VT2. There were significant differences among groups post-training: the Meso-ecto and the Meso groups showed the greatest improvements in aerobic capacity.

Conclusion: The significant somatotype-aerobic training interaction suggests different trainability with intermittent and individualised aerobic training according to somatotype.

Methods

Subjects
Forty one fit physical education students volunteered to participate in this study. They did not practice any sport but undertook ~10 h per week of various physical activities as part of their university course. Aged 21.4 ± 1.3 years, they were divided into four somatometric groups (fig 1). Body composition was estimated from skinfold thickness. The anthropometric characteristics are presented in table 1. The study was approved by the University Ethics Committee. After receiving a detailed explanation of the potential benefits and risks associated with participation in the study, the authors sought to determine the best predictors of 10 km running time, have shown that the somatotype and anthropometric traits of athletes contribute significantly to variance in endurance performance. However, the main physiological determinants of running endurance performance, that is $V_{O2\text{max}}$, the second VT, exercise economy, and velocity at $V_{O2\text{max}}$, were not included in the study’s stepwise multiple regression analysis. Furthermore, the influence of somatotype on aerobic fitness trainability was not considered.

The aim of the present study was therefore to investigate the interaction between somatotype and the adaptation of the key aerobic capacity variables to individualised intermittent aerobic training in male white North African students.

Abbreviations: ACE, angiotensin converting enzyme; ANCOVA, analysis of covariance; ANOVA, analysis of variance; HR, heart rate; RER, respiratory exchange ratio; $V_{O2\text{max}}$, maximal oxygen uptake; VT, ventilatory threshold
USA). The average of the three measurements for each site was considered in the calculation. The right side values for skinfolds, girths, and diameters were included in the calculations according to the method described by Ross et al.12

Each subject performed three preliminary tests 1 week apart. The first test measured VO\textsubscript{2max} and was performed in the laboratory. The second test, that is the VAM-EVAL track test,13 measured maximal aerobic speed (t\textsubscript{V\textsubscript{O}2max}), and the third test assessed the time to exhaustion at 100% \textit{vVO\textsubscript{2max}} on the running track (t\textsubscript{lim100}).

**\textit{VO}\textsubscript{2max} measurement**

Individual \textit{VO}\textsubscript{2max} was measured during a continuous, incremental test to exhaustion14 on an electronically braked cycle ergometer (Monark Ergometrics 800, Bitz, Germany). Prior to the test, the subjects underwent clinical examination to check their health status. Respiratory parameters (\textit{VO}\textsubscript{2}, \textit{CO\textsubscript{2}}) and respiratory exchange ratio (RER) were measured continuously (ZAN 680, Oberthulba, Germany) during the initial resting period and throughout the test until exhaustion. The gas analysers were calibrated before each test with gases of known concentrations. Heart rate (HR) was recorded with an ECG monitoring system. The following criteria15 indicated \textit{VO}\textsubscript{2max} had been attained: (i) a plateau or slight drop in \textit{VO}\textsubscript{2} despite an increase in workload; (ii) exhaustion; (iii) an RER above 1.1; and (iv) an HR above 95% of predicted maximal HR. The second ventilatory threshold (VT\textsubscript{2})16 and maximal oxygen pulse (O\textsubscript{2} pulse) were then quantified. VT\textsubscript{2} was assessed independently by two experienced individuals who then compared their results and reached a consensus. VT\textsubscript{2} was expressed in \textit{VO}\textsubscript{2} (ml kg\textsuperscript{-1} min\textsuperscript{-1}) and as a fraction of \textit{VO}\textsubscript{2max} (%\textit{VO}\textsubscript{2max}). Maximal \textit{O\textsubscript{2}} pulse (ml beats\textsuperscript{-1}) was calculated by dividing \textit{VO}\textsubscript{2max} (ml min\textsuperscript{-1}) by maximal HR (HR\textsubscript{max}), the highest HR attained at exhaustion. \textit{VO}\textsubscript{2max} was expressed classically and according to allometric scaling to avoid underestimation in heavy and overestimation in light individuals.17

**VAM-EVAL track test**

The VAM-EVAL track test13 took place on a 400 m track with cones placed every 20 m. A pre-recorded soundtrack indicated with brief sounds the instant when the subject had to pass near a cone to maintain the imposed speed. A longer sound marked a change of stage. The first stage was set at 8 km h\textsuperscript{-1} with subsequent increments of 0.5 km h\textsuperscript{-1} per 1 min stages. The test was finished when the subject was unable to maintain the imposed running speed. The speed corresponding to the last completed stage was recorded as \textit{VO}\textsubscript{2max} (km h\textsuperscript{-1}).

**Time to exhaustion at 100% \textit{vVO\textsubscript{2max}} (t\textsubscript{lim100})**

The purpose of the third field session was to estimate the individual running performance at 100% \textit{vVO\textsubscript{2max}} (t\textsubscript{lim100}). The test took place on the same track described above. After a

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Physical characteristics of each group separated according to somatotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>Somatotype characteristics</td>
<td>Endo-meso, n = 9</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>(77.7 \pm 6.1)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>(178.9 \pm 5.6)</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>(20.6 \pm 2.2)</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>(16.0 \pm 2.1)</td>
</tr>
<tr>
<td>Lean mass (kg)</td>
<td>(61.7 \pm 5.2)</td>
</tr>
<tr>
<td>BMI (kg m\textsuperscript{-2})</td>
<td>(24 \pm 1.0)</td>
</tr>
<tr>
<td>Endomorphy</td>
<td>(4.1 \pm 0.5)</td>
</tr>
<tr>
<td>Mesomorphy</td>
<td>(2.1 \pm 0.3)</td>
</tr>
</tbody>
</table>

BMI, body mass index; Ecto, ectomorph; Endo-meso, endomorph-mesomorph; Meso, mesomorph; Meso-ecto, mesomorph-ectomorph. Values are expressed as mean ± SD.
15 min warm up at 60% $\dot{V}O_{2\text{max}}$ the subjects had to run for as long as possible at a pace corresponding to their $\dot{V}O_{2\text{max}}$. The post-training tlim100 was performed at the pre-training $\dot{V}O_{2\text{max}}$.

**Training**

The training program lasted 12 weeks with two sessions per week, and consisted of individualised intermittent running. Each training session began with a 20 min warm up at 60% of each subject's $\dot{V}O_{2\text{max}}$. The session itself was composed of the maximal number of running fractions that each subject was able to perform. Each fraction consisted of one period of running at 100% of $\dot{V}O_{2\text{max}}$ and one period of active recovery at 60% of $\dot{V}O_{2\text{max}}$. The duration of each period was equal to half the individual tlim100 duration. To establish the maximal number of fractions that each subject could perform during a session, an individualised test was performed before the start of the training program. Thus, the training program was individualised both for the running speed for intervals and for the number of fractions. The intensities of the periods of exercise and recovery were readjusted after 6 weeks by way of a VAM-EVAL test (intermediate $\dot{V}O_{2\text{max}}$). After training, $\dot{V}O_{2\text{max}}$, $\dot{V}O_{2\text{max}}$ and tlim100 (performed at the pre-training $\dot{V}O_{2\text{max}}$) were measured for each subject.

**Statistical analysis**

A somatochart was developed with Somatotype 1.0 software to determine the somatotypes (fig 1). Four distinct groups emerged with nine endomorph-mesomorph (Endo-meso), 11 mesomorph (Meso), 12 mesomorph-ectomorph (Meso-ecto), and nine ectomorph subjects (Ecto). The data were grouped by dominant somatotype and descriptive statistics were expressed as mean ± SD. The hypothesis that somatotype impacts improvements in aerobic fitness variables was tested for significance at an $\alpha = 0.05$ level by two way analysis of variance (ANOVA) for repeated measures. An analysis of covariance (ANCOVA) was used post hoc to compare means for each variable in the presence of significant somatotype-aerobic training period interaction effects. Differences between pre- and post-training mean values were evaluated for significant ($p<0.05$) changes from 0 by the paired Wilcoxon test (SPSS 10.0).

**RESULTS**

ANOVA indicated significant training effects for all physiological variables from pre- to post-training within groups ($p<0.001$) except for maximal HR (table 2). A significant (somatotype x pre- and post-training) interaction effect ($p<0.001$) was observed. This interaction mainly concerned $\dot{V}O_{2\text{max}}$, $\dot{V}O_{2\text{max}}$ expressed in ml kg$^{-1}$ min$^{-1}$ and ml kg$^{-0.75}$ min$^{-1}$, and $\dot{V}O_2$ at VT2 (fig 2).

$v\dot{V}O_{2\text{max}}$ and tlim100

$v\dot{V}O_{2\text{max}}$ increased significantly in the four groups after the training period (table 2). Significant (somatotype x pre- and post-training) interaction effects ($F = 9.70$ (df 1, 37); $p<0.001$) were also observed. Meso-ecto subjects showed the greatest increment in $v\dot{V}O_{2\text{max}}$. Significant elevation of tlim100 (performed at the pre-test $v\dot{V}O_{2\text{max}}$) was evident for all somatotype groups (table 2), but the mean increases were not significantly different between groups.

$\dot{V}O_{2\text{max}}$

Both absolute (l min$^{-1}$) and relative $\dot{V}O_{2\text{max}}$ (ml kg$^{-1}$ min$^{-1}$ and ml kg$^{-0.75}$ min$^{-1}$) increased significantly in the four groups except for absolute $\dot{V}O_{2\text{max}}$ in Endo-meso subjects which only showed a trend towards significance ($p = 0.08$, table 2). However, interaction effects (somatotype x pre- and post-training) were significant ($F = 22.7$ (df 1, 37); $p<0.001$) only for relative $\dot{V}O_{2\text{max}}$ (ml kg$^{-1}$ min$^{-1}$ and ml kg$^{-0.75}$ min$^{-1}$). The Meso-ecto and Meso groups experienced significantly greater improvements than the other groups (fig 2B1,B2).

Figure 2  Somatotype-aerobic training interaction effects on cardiorespiratory parameters. The numbers on the columns represent the percentage of change from test to retest; **$p<0.01$. For legends, see table 1.
The main findings of our study showed that the most significant improvements in aerobic capacity components following the training program varied among the dominant somatotype groups. This indicates that the individualisation of training parameters, such as intensity and duration, is crucial for maximizing training gains. The highest improvements in aerobic capacity were observed in the Meso-ecto group (8.2%) compared to the Endo-meso group (6.7%) and Meso group (4.5%). The post-training improvements in relative VO$_2$max (ml kg$^{-1}$ min$^{-1}$) were significantly higher for the Meso-ecto and Meso groups (15.3% and 12.7%, respectively) than for the Endo-meso group (8.2%). These mean gains are consistent with values found in other training studies which have reported increases ranging from 10% to 23%. The increments in VO$_2$max could be explained by augmented stroke volume, and by enhanced potential for widening the arterial-venous oxygen difference during exercise and/or by both factors. The improvements in relative VO$_2$max (ml kg$^{-1}$ min$^{-1}$ and ml kg$^{-1}$ 0.75 min$^{-1}$) in the present study could be due to improved capacity of the cardiorespiratory system and not to any change in body mass. The rise in O$_2$ pulse following the training period may reflect the extent of cardiac and peripheral adaptation to training.

The training program also induced a significant improvement in VO$_2$max. The magnitude of these increases (from 6.1% to 8.2%) differed among somatotype groups. The Meso-ecto group showed the highest mean gains (8.2%). This improvement in VO$_2$max indicates that a certain percentage of VO$_2$max will be associated with higher speed after endurance training. Several studies have reported increased VO$_2$max of between 2.9% and 8.5% in well-trained athletes following endurance training. They found that this increase in VO$_2$max resulted from significant improvements in both VO$_2$max and running economy. In the present study, improvements in the former were shown while the latter variable was not measured.

VO$_2$ at VT2
Oxygen uptake at VT2 expressed in ml kg$^{-1}$ min$^{-1}$ and in percentage of VO$_2$max (%VO$_2$max) showed a significant increase pre- to post-training for all groups except for %VO$_2$max in the Endo-meso group (table 2). However, interaction effects (somatotype$x$pre- and post-training) were significant ($F = 16.3$ (df 1, 37); $p < 0.001$) only in VT2 expressed in ml min$^{-1}$ kg$^{-1}$; the Meso-ecto group presented a significantly higher mean of increases compared to the other groups.

Maximal O$_2$ pulse
No significant interaction effects (somatotype$x$pre- and post-training) were noted. However, there was a significant improvement in all somatotype subjects from pre- to post-training (table 2) except for the Endo-meso group.

**DISCUSSION**

The results of this study showed the effects of somatotype on adaptation of aerobic capacity to individualised aerobic interval training in white North African male students. The variations in aerobic capacity variables demonstrated a significant interaction effect with somatotype over a period of aerobic training. The magnitude of increase in these parameters varied according to somatotype group. Indeed, as a result of training, $v$VO$_2$max, VO$_2$max (ml kg$^{-1}$ min$^{-1}$ and ml kg$^{-1}$ 0.75 min$^{-1}$), and VO$_2$ at VT2 improved in all training groups, with the Meso-ecto and Meso groups showing the highest training gains.

The objective of the interval training program was mainly to elicit optimal improvements in aerobic capacity variables. The frequency, intensity, and duration of the training program were established as essential components in promoting adaptive responses to training. Individual $v$VO$_2$max was considered as a relevant criterion to set training intensities. In the present study, $v$VO$_2$max measurement in the field, for training purposes, was preferred to laboratory measurements. The time for which exercise at $v$VO$_2$max could be sustained (tim100) was used to individualise the duration of interval training at $v$VO$_2$max according to the method of Billat et al. The number of repetitions performed by subjects in the previously individualised intermittent protocols varied from 2 to 5. The mean values recorded by Billat et al. in long distance runners were 5.5 ± 2.0 repetitions. This is the reason why the number of repetitions in training sessions was individualised and not standardised.

**Table 2** Effects of 12 week training program on components of aerobic capacity in somatotype groups

<table>
<thead>
<tr>
<th></th>
<th>Endo-meso, n = 9</th>
<th>Meso, n = 11</th>
<th>Meso-ecto, n = 12</th>
<th>Ecto, n = 41</th>
<th>Total, n = 41</th>
<th>Interaction, df 1, 37</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v$VO$_2$max (km h$^{-1}$)</td>
<td>Pre-test 15.7 ± 1.0</td>
<td>16.4 ± 1.1</td>
<td>16.4 ± 0.9</td>
<td>16.2 ± 0.9</td>
<td>16.2 ± 1.0</td>
<td>F = 9.7</td>
</tr>
<tr>
<td>tim100 (s)</td>
<td>Pre-test 345.6 ± 70.0</td>
<td>306.8 ± 64.5</td>
<td>298.4 ± 103.8</td>
<td>280.9 ± 64.1</td>
<td>307.2 ± 79.5</td>
<td>F = 1.5</td>
</tr>
<tr>
<td>VO$_2$max (l min$^{-1}$)</td>
<td>Pre-test 3.9 ± 0.5</td>
<td>4.2 ± 0.5</td>
<td>3.3 ± 0.5</td>
<td>3.3 ± 0.2</td>
<td>3.7 ± 0.6</td>
<td>F = 1.5</td>
</tr>
<tr>
<td>%VO$_2$max</td>
<td>Pre-test 50.7 ± 4.6</td>
<td>56.4 ± 4.7</td>
<td>54.2 ± 5.7</td>
<td>48.5 ± 4.8</td>
<td>52.8 ± 5.7</td>
<td>F = 22.6</td>
</tr>
<tr>
<td>Maximal O$_2$ pulse</td>
<td>Pre-test 21.3 ± 3.4</td>
<td>24.5 ± 2.8</td>
<td>21.8 ± 2.5</td>
<td>18.3 ± 1.6</td>
<td>21.9 ± 3.4</td>
<td>NS</td>
</tr>
<tr>
<td>HR max</td>
<td>Pre-test 184.7 ± 9.2</td>
<td>190.7 ± 6.5</td>
<td>187.3 ± 7.5</td>
<td>191.1 ± 7.8</td>
<td>188.5 ± 7.8</td>
<td>F = 2.07</td>
</tr>
<tr>
<td>(beats min$^{-1}$)</td>
<td>Pre-test 21.1 ± 2.7</td>
<td>22.0 ± 3.2</td>
<td>18.8 ± 3.0</td>
<td>17.1 ± 1.7</td>
<td>19.8 ± 3.3</td>
<td>F = 1.5</td>
</tr>
<tr>
<td>(ml beat$^{-1}$)</td>
<td>Pre-test 22.0 ± 3.4</td>
<td>24.5 ± 2.8</td>
<td>21.8 ± 2.5</td>
<td>18.3 ± 1.6</td>
<td>21.9 ± 3.4</td>
<td>NS</td>
</tr>
</tbody>
</table>

NS, not significant; **p<0.01. For legends, see table 1.
somatotype groups. Indeed, mean gains in $\dot{V}O_{2\text{max}}$, relative $V_{\text{O}2\text{max}}$ (expressed per ml kg$^{-1}$ min$^{-1}$ and per ml kg$^{-0.75}$ min$^{-1}$), and $V_{\text{O}2}$ at VT2 were higher when the Meso and Ecto components were balanced as is the case in the Ecto-meso group. Improvements were slightly lower in subjects exhibiting a Meso dominance. Thus, a morphological type favouring cardiorespiratory adaptation to aerobic training seems to exist. Quantification of the contribution of the dominant somatotype to improvement in aerobic fitness is difficult. However, studies of monozygote and heterozygote twins and other subjects with familial similarities have shown appreciable genetic effects on somatotype, especially at the level of the Ecto component. On the other hand, $V_{\text{O}2\text{max}}$ and an index of aerobic fitness, is influenced by genetic and environmental factors. Genetic factors indeed impact the development of $V_{\text{O}2\text{max}}$ but training allows its improvement. The same author showed that heredity largely influences the trainability of $V_{\text{O}2\text{max}}$. Depending on genotype, the same training program can have different effects, ranging from 0% to 30%. According to these studies, there is a potential association between genetic variables, such as muscular enzymes (that is mitochondrial DNA), and changes in $V_{\text{O}2\text{max}}$ following training. Nevertheless, in contrast to somatotype determination, which is quite easy, studying the genetic type of an athlete is, at present, somewhat problematic. A new issue, which has recently been raised and could help explain differences in responses to endurance training, is the role played by the angiotensin converting enzyme gene (ACE) especially its 1 allele variant. One possible explanation for the great improvement in aerobic capacity in the Meso-ecto and Meso groups is the higher prevalence of the ACE gene insertion polymorphism in these groups.

In addition, somatotype-aerobic training interaction effects on improvement in aerobic capacity are also influenced by the relationship between $V_{\text{O}2\text{max}}$ and biometric data, such as body size, body mass, and body surface. Thus, the allometric approach is used to compare individuals of various dimensions and sizes. Many studies have shown that relative $V_{\text{O}2\text{max}}$ is negatively correlated to body mass. However, it also appears important to consider how segments are distributed. As indicated by Cavanagh and Kram as regards running, a higher energy cost was recorded when the lower limbs were heavier. Body dimensions also influence running energy cost, but a relatively conflicting report has been presented on this topic. These factors should be considered by researchers attempting to further explain the interaction between somatotype and the effect of aerobic training. Fat mass also may have influenced aerobic capacity. Most studies have reported that high levels of adiposity reduce aerobic capacity expressed relative to body mass. Finally, differences in ethnic/racial origins should also be taken into account when interpreting the results of subjects differing in racial origin. This point is not addressed in the present study because all subjects were of the same background. Moreover, somatotype measurement is based on several criteria which are independent of ethnic origin. To the best of our knowledge and according to the literature, there are no differences in trainability between black and white subjects of the same somatotype group.

The results of our investigation suggest that somatotype may partly explain the variance in physiological adaptive responses to aerobic interval training. Anthropometric traits which characterise the Meso-ecto and Meso somatotype subjects may explain these differences. However, it seems that genetic factors play a considerable role in the expression of physiological adaptation to which the somatotype-training association may make an important contribution.

In conclusion, the results of the present study indicate significant somatotype-aerobic training interaction effects that may make an important contribution to the establishment of an adaptive response to intermittent and individualised aerobic training. Somatotype mainly influenced gains in aerobic capacity, particularly $\dot{V}O_{2\text{max}}$, relative $V_{\text{O}2\text{max}}$ and relative $V_{\text{O}2}$ at the second VT. Significant post-training differences among groups were observed; Meso-ecto and Meso subjects seemed to be particularly predisposed to benefit from aerobic training. The relationship of aerobic fitness trainability to somatotype and genetic factors warrants further investigation.

Conclusions
This study demonstrates that somatotype is a structural factor in aerobic fitness trainability and could be helpful when identifying talented individuals for endurance events. Nevertheless, it is not easy to establish with precision the contribution of somatotype-training interaction effects to aerobic capacity determinants. Many factors, including genetic contribution, may be determinants of both somatotype and the capacity to adapt to training; this could be further investigated.

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References
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