SHORT COMMUNICATION

Whole Body Fat Free Mass and $\dot{V}O_{2peak}$ in Recreationally Active Men and Women

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BACKGROUND: $\dot{V}O_{2peak}$ has traditionally been thought to be regulated by cardiac output and arteriovenous-oxygen difference. A "muscle-centric" view suggests the cardiovascular system is secondarily responsive to the primary driver: active muscle mass.

METHODS: A total of 19 recreationally active men ($N = 10$) and women ($N = 9$) performed a $\dot{V}O_{2peak}$ test, a $\dot{V}O_{2peak}$ verification test on an electrically braked cycle ergometer on the same day, and a hydrostatic weighing test to assess fat free mass after providing written informed consent.

RESULTS: $\dot{V}O_{2peak}$ was significantly higher in men (3.74 ± 0.6 L · min^{-1}) than women (2.22 ± 0.30 L · min^{-1}). Whole body fat free mass explained 91% of the variability in $\dot{V}O_{2peak}$ ($R^2 = 0.91$) in the men and women combined, 81% of the variability in $\dot{V}O_{2peak}$ in men alone, and 46% of the variability in $\dot{V}O_{2peak}$ in women alone. None of these subjects were highly trained.

DISCUSSION: Fat free mass, a surrogate for muscle mass, was the primary predictor of $\dot{V}O_{2peak}$ in this group of recreationally active men and women. Therefore, it appears that whole body fat free mass (a surrogate for muscle mass) is the primary driver for $\dot{V}O_{2peak}$ in these recreationally active men and women. These data have implications as to the type of training NASA personnel should be undertaking: resistance training as opposed to aerobic training.

KEYWORDS: skeletal muscle, stroke volume, maximal oxygen consumption.

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Peak oxygen consumption ($\dot{V}O_{2peak}$) is determined by many factors. Clearly, this measure of physical fitness is thought to be the result of peak heart rate, peak stroke volume,[9] and peak arteriovenous-oxygen difference (A-$\dot{V}O_{2diff}$).[1] Peak stroke volume is largely determined by the Frank-Starling Law,[4] whereas peak A-$\dot{V}O_{2diff}$ is thought to be the result of mitochondrial density[4] and the number of capillaries per fiber.[9] However, it is clear that peak stroke volume is directly controlled by the "muscle-pump," leading to increased venous return due to muscular contraction and, therefore, an indirect or involuntary mechanism for alterations in $\dot{V}O_{2peak}$ with direct or voluntary control coming from central motor drive originating in the cerebral cortex. Adding muscle with sufficient mitochondrial density and number of capillaries per fiber to contracting muscle mass would increase $\dot{V}O_{2peak}$ due to an increase in A-$\dot{V}O_{2diff}$ and an increase in stroke volume (muscle pump).[7] Therefore, we examined the relationship between whole body fat free mass and $\dot{V}O_{2peak}$ and hypothesized that there may be a strong relationship between this surrogate for muscle mass and $\dot{V}O_{2peak}$ in recreationally active men and women. Further, we evaluated men and women separately with regard to this relationship.

METHODS

The study protocol was approved in advance by the University of Louisville Institutional Review Board. There were 10 recreationally active men and 9 recreationally active women who participated in this investigation after giving written informed consent. Please see Lambert et al.[8] for a detailed description of

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the activity level of the study participants and the descriptive statistics for these subjects.

The details of the testing procedures can also be found in Lambert et al.[8] Briefly, subjects cycled continuously on a Lode (Corival) electrically braked cycle ergometer (Groningen, Netherlands). The initial stage was 50 W for women and 100 W for men with 25-W increases every 3 min for three stages followed by a 25-W increase every minute thereafter. A single-stage test verification of $\dot{V}O_{2peak}$ to ensure a valid initial test was performed 15 min after the initial assessment with the Watts set 25 W higher than the peak Watts corresponding to $\dot{V}O_{2peak}$. Respiratory gases were analyzed for oxygen and carbon dioxide and volume using a Parvomedics metabolic gas analyzer (TrueMax 2400; Sandy, UT, USA). Peak $\dot{V}O_2$ was averaged from the $\dot{V}O_{2peak}$ test and the verification test for subsequent use in this paper. Hydrostatic weighing was used on a separate day for the determination of fat free mass (kg) using the equations of Brozek et al.[1]

Statistical Analysis

A Pearson product moment correlation was performed using the Excel program from Microsoft Office 2013 between fat free mass and $\dot{V}O_{2peak}$ for the total of 19 men and women, for the 10 men, and for the 9 women.

RESULTS

Women (2.22 ± 0.30 L · min^{-1}) had a significantly lower $\dot{V}O_{2peak}$ than men (3.74 ± 0.61 L · min^{-1}; $P < 0.05$). There was a statistically significant and very strong relationship ($R^2 = 0.91$; $P < 0.05$; **Fig. 1**) between whole body fat free mass and $\dot{V}O_{2peak}$ in this group of 19 men and women when pooled together. When one potential outlier was removed ($N = 18$), the relationship was still very strong (R^2 was 0.89; $P < 0.05$). The relationship was also very strong when only men were examined ($R^2 = 0.81$; $P < 0.05$; **Fig. 2**). When only women were examined the relationship was still statistically significant and still of high magnitude with 46% of the variability in $\dot{V}O_{2peak}$ being explained by fat free mass ($R^2 = 0.46$; $P < 0.05$; **Fig. 3**).

DISCUSSION

The major finding of this investigation was that whole-body fat free mass explained 91% of the variability in $\dot{V}O_{2peak}$ in a group of 19 recreationally active, young men and women. This relationship was maintained when men were studied ($R^2 = 0.81$) and, although of smaller magnitude, was also maintained in women ($R^2 = 0.46$).

The determinants of $\dot{V}O_{2peak}$ have traditionally been thought to be peak stroke volume[1] and peak A-$\dot{V}O_{2diff}$.[1] However, it appears from my data and those of others[2,3,5] that a morphological difference (increased fat free mass or increased muscle mass) could be a major determinant of $\dot{V}O_{2peak}$. From a mechanistic perspective, adding fat free mass (a surrogate for muscle mass), if of sufficient oxidative capacity (mitochondrial density, myoglobin content, and capillarity), would logically increase oxygen consumption expressed in absolute terms (L · min^{-1}).[6] These data are supported by at least three other studies[2,3,5] in which a statistically significant relationship was found between fat free mass or muscle mass and $\dot{V}O_{2max}$ or $\dot{V}O_{2peak}$. Kim et al.[6] reported a statistically significant ($P < 0.05$) and strong relationship between leg muscle mass and $\dot{V}O_{2max}$ in young men and women ($R^2 = 0.613$) and older men and women ($R^2 = 0.764$ $P < 0.05$) for cycling. Further, Weiss et al.[10] reported a ~4% loss in lower extremity muscle mass with ~7% weight loss and a ~6% statistically significant reduction in absolute $\dot{V}O_{2max}$. I know of no data where muscle oxidative capacity per unit of muscle goes down with weight loss. Therefore, the loss of muscle mass was predictive of the loss in $\dot{V}O_{2max}$. Both of these studies suggest a strong relationship between lower leg muscle mass and absolute $\dot{V}O_{2max}$. Because the subjects in the present study were not highly trained but recreationally active, I have no reason to believe this relationship between whole body fat free mass and $\dot{V}O_{2peak}$ is a spurious one.

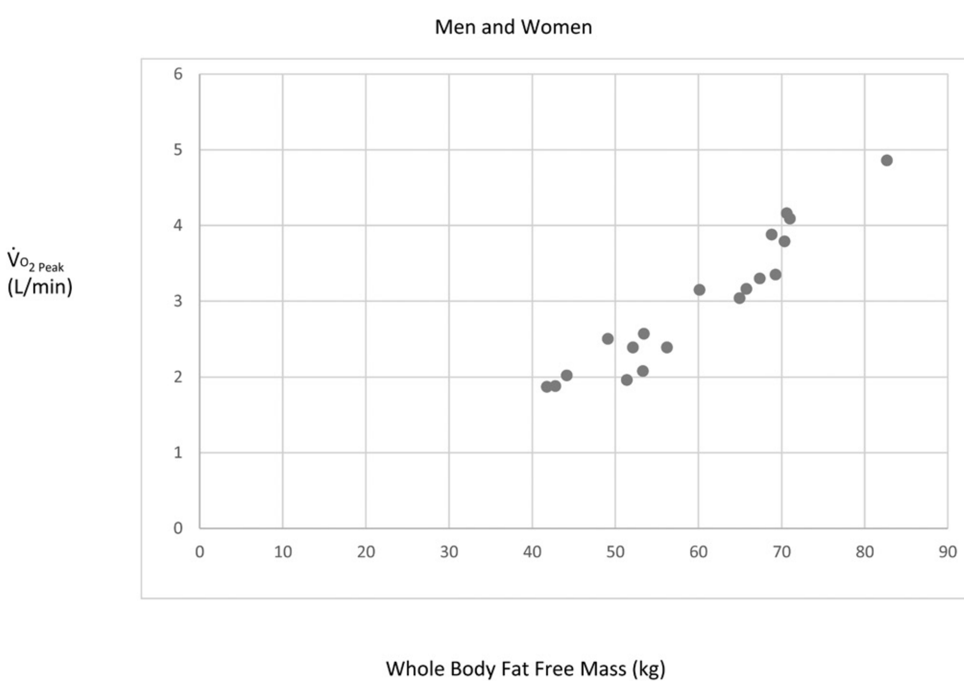

Fig. 1. Relationship between whole body fat free mass (kg) and $\dot{V}O_{2peak}$ (L · min^{-1}) in 19 recreationally trained men and women.

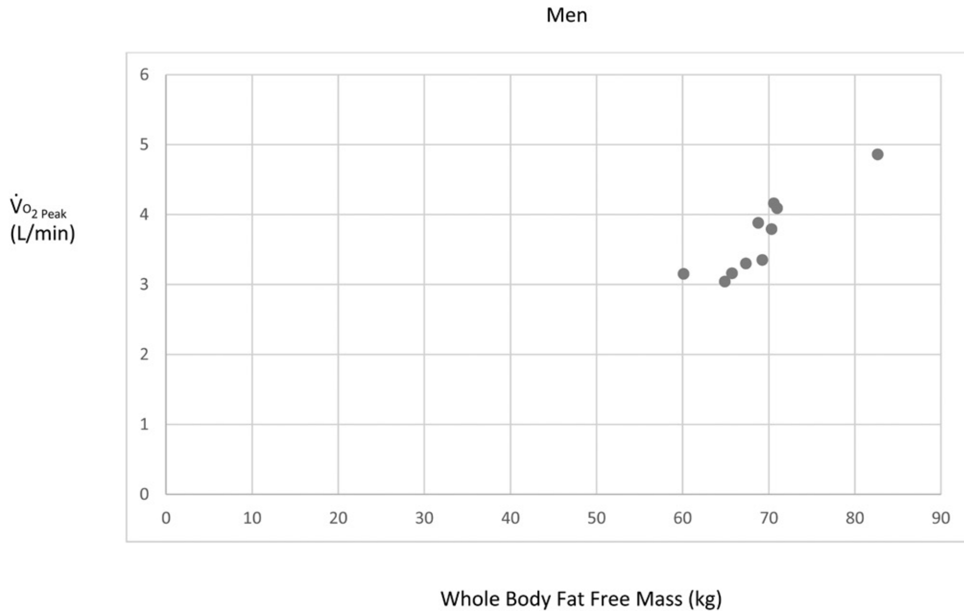

Fig. 2. Relationship between whole body fat free mass (kg) and $\dot{V}O_{2peak}$ ($L \cdot min^{-1}$) in 10 recreationally trained men.

However, in these recreationally trained individuals it appears that 91% of the variability in $\dot{V}O_{2peak}$ was explained by whole body fat free mass. Thus, in recreationally trained individuals, but possibly not in highly trained individuals, fat free mass is the primary determinant of $\dot{V}O_{2peak}$.

These data are extremely important and have implications for exercise training to improve $\dot{V}O_{2peak}$. Indeed, muscle mass (as evidenced by fat free mass) predicts 91% of the variability in $\dot{V}O_{2peak}$ in these recreationally active individuals. Therefore, training to increase muscle mass (if muscle oxidative capacity is unchanged) of the prime mover muscle groups likely will be of benefit to increase $\dot{V}O_{2peak}$ during activities specific to that prime mover group. Clearly, this would appear to be important for training for individuals such as NASA personnel who have limited time to train and want to maximize both anaerobic and aerobic adaptations. Longitudinal studies need to be undertaken which result in increases in muscle mass, i.e., resistance exercise training, and $\dot{V}O_{2peak}$ analysis using those specific muscle groups. It must be noted that these data were obtained on a cycle ergometer. These findings and implications may only be specific to non-weight-bearing activities such as cycling as opposed to weight-bearing activities such as walking or running.

The operative mechanism for the strong relationship between whole body fat free mass and $\dot{V}O_{2peak}$ would seem to reside in an increase in absolute A-$\dot{V}O_2$ difference (i.e., not expressed relative to body mass or muscle mass) as contracting a bigger muscle will result in a greater oxygen uptake than contracting a smaller muscle ($ml \cdot min^{-1}$). Although an increase in venous return and, therefore, an increase in peak stroke volume cannot be ruled out as a result of a greater "muscle pump", a greater amount of contracting skeletal muscle does indeed increase venous return.[7,10]

Clearly fat free mass or muscle mass is not the only determinant of $\dot{V}O_{2peak/max}$ in highly trained individuals. Muscle oxidative capacity increases due to training, including myosin changes to a slower more oxidative phenotype, increased mitochondrial density/number, and an increased number of capillaries.[11]

In conclusion, I found a strong relationship between whole body fat free mass and whole body $\dot{V}O_{2peak}$ in a group of 19 recreationally active men and women. This finding suggests that active muscle mass is predictive of $\dot{V}O_{2max}$ in recreationally active men and women. Whole body fat free mass is a surrogate for muscle mass. Thus, in this group of recreationally active individuals, muscle mass strongly predicts $\dot{V}O_{2peak}$. As opposed to aerobic or endurance exercise, the best way to increase muscle mass is through resistance training, i.e., relatively few contractions with high loads (force). Therefore, individuals, such as NASA personnel who wish to maintain muscle mass, bone density, and aerobic fitness in space, should spend the majority of their time training with resistance exercise rather than endurance or aerobic exercise.

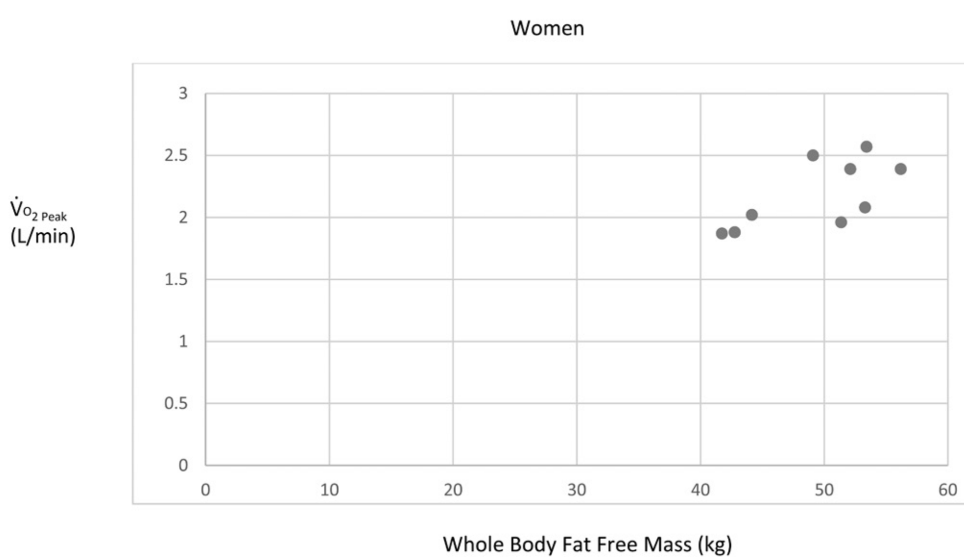

Fig. 3. Relationship between whole body fat free mass (kg) and $\dot{V}O_{2peak}$ ($L \cdot min^{-1}$) in 9 recreationally trained women.

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