Maximal Oxygen Uptake in Children of Different Body Mass

Should maximal oxygen uptake be expressed differently for children of different body mass?

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This Master's Thesis is carried out as a part of the education at the University of Agder and is therefore approved as a part of this education. However, this does not imply that the University answers for the methods that are used or the conclusions that are drawn.

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Forord

Denne oppgaven om oksygenopptak og barn har vært lærerik og bra, selv om det ikke var mitt første valg. Men av personlige årsaker i høst, ble det bestemt i samråd med veileder at det var lurest å bytte, så jeg kom i gang.

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Contents

Abstract

Background: Maximal oxygen uptake ($\dot{V}O_{2\max}$) has important implications for current and future health in children. There is ongoing debate on how to express $\dot{V}O_{2\max}$ in children and adolescents. **Objectives:** Are scaling factors different in obese and normal weight children and between genders? How does percentage fat influence aerobic fitness? **Methods:** 57 obese (30 girls) and 79 children of normal weight (38girls) in the age 7-17 years were include in the present study. $\dot{V}O_{2\max}$ were measured during a treadmill running test, were both the incline and speed increased until subjects were exhausted. Body compositions were measured with dual-energy X-ray absorptiometry (DXA) or a Harpenden fat caliper. Allometric scaling factors were calculated using linear regression of log-transformed data. **Results:** Allometric scaling factors were 0.51 for obese girls, 0.53 for normal weight girls, 0.47 for obese boys and 0.27 for normal weight boys. Obese boys had almost the same allometric scaling factor (0.47) as girls, and normal weight boys (0.27) had the lowest scaling factor of all subjects. **Conclusion:** findings in the present study demonstrate that use of mass exponent when comparing $\dot{V}O_{2\max}$ in obese and normal weight children. It seems that percentage fat doesn't have a great influence on children's $\dot{V}O_{2\max}$. The difference between obese and normal weight children has to be due to other factors than percentage fat.

Key words: allometric scaling, children, maximal oxygen uptake, normal weight, obese

Sammendrag

Bakgrunn: Maksimalt oksygen opptak har stor betydning for nåværende og fremtidig helse hos barn. Det er en debatt om hvordan man skal og bør uttrykke $\dot{V}O_{2\max}$ på barn og unge. **Hensikt:** Finne en skaleringsfaktor for barn av forskjellig kjønn og forskjellig kroppssammensetning. Hvordan fettprosent påvirker VO2max. Både fete og normal vektige gutter og jenter ble inkludert. **Metode:** 57 fete (30 jenter) og 79 normal vektige (38 jenter) barn i alderen 7-17 år ble inkludert. $\dot{V}O_{2\max}$ ble målt ved løp på tredemølle, hvor fart og hellning økte til deltakeren var utmattet. Kroppssammensetning ble målt ved hjelp av røntgen stråling (DXA) eller Harpenden fett kalipper. Allometriske vekteksponenter ble funnet ved hjelp av en lineær regresjonsanalyse av log-transformerte data. **Resultat:** Allometriske vekteksponenter var 0.51 for fete jenter, 0.53 for normal vektige jenter, 0.47 for fete gutter og 0.27for normal vektige gutter. **Konklusjon:** funnene i denne studien illustrerer viktigheten ved bruk av vekteksponent når en sammenlikner $\dot{V}O_{2\max}$ mellom fete og normalvektige barn. Fett prosent ser ikke ut til å spille en stor rolle for $\dot{V}O_{2\max}$ hos barn. $\dot{V}O_{2\max}$ forskjellene ser ut til å være andre årsaker enn fettprosenten til barn.

Nøkkelord: allometrisk skalering, barn, maksimalt oksygenopptak, normalvektig, fet

1. Introduction

The ability to perform aerobic exercise is associated with the individual's maximal oxygen uptake ($\dot{V}O_{2\max}$) [1]. $\dot{V}O_{2\max}$ is the highest rate of consumed oxygen during exercise [2], and it is an important marker for health. Poor $\dot{V}O_{2\max}$ has, in children, been associated with risk factors for cardiovascular diseases [1, 2, 3, 4, 5]. $\dot{V}O_{2\max}$ can be expressed in absolute term $(l \cdot min^{-1})$ or relative to body mass $(ml \cdot kg^{-1} \cdot min^{-1})$[6].

There seems to be a great difference between boys and girls in $\dot{V}O_{2\max}$. Boys $\dot{V}O_{2\max}$ values are higher than the values of the girls even before puberty [1, 3]. When $\dot{V}O_{2\max}$ is expressed related to body mass, no changes are observed during childhood and adolescents for boys. For girls, though, there is a progressive decline observed in mass-relative $\dot{V}O_{2\max}$ from age 8 [2, 4, 5]. In boys the increase in $\dot{V}O_{2\max}$ with increasing age has been attributed to greater muscle mass and higher hemoglobin concentration. The reason for the decline in girls is less clear, but it seems that this can be explained by the increased fat percentage and body mass [2, 1, 3, 4, 5].

Several researchers have discussed how to express $\dot{V}O_{2\max}$ in children according to different body composition, body mass, and muscle mass and fat mass; although, $\dot{V}O_{2\max}$ relative to body mass is common [3, 7, 8, 9, 10, 11, 12, 13]. It seems to be a disagreement among researchers in how to express $\dot{V}O_{2\max}$ in children. There are several suggestions from several researchers; 0.81 and 0.61 [14], 0.46 [15], 0.68 and 0.37 [10], 0.52 and 0.55 [11], 0.71[4], 0.91 [16] and 0.78 [13]. An agreement among researchers seems to be that $\dot{V}O_{2\max}$ should not be expressed in relation to total body mass. According to Pettersen et al., [17] 0.67 together with 0.75 are the most frequently used exponents when comparing children's $\dot{V}O_{2\max}$.

The study is important because the majority of the earlier done studies haven't included both obese and normal weight children of both genders [18, 8, 13, 7, 3].

1.1 Objectives

- Are scaling factors different in obese and normal weight children and between genders?
- How does percentage fat influence aerobic fitness?

2. Theoretical Background

The ability to perform aerobic exercise is influenced by the individual's maximal oxygen uptake, which is known as one of the most important indexes of cardio respiratory fitness [1, 17]. According to Armstrong [2] $\dot{V}O_{2\max}$ depends upon pulmonary, cardiovascular, and hematological components of oxygen delivery and the oxidative mechanisms of the exercising muscle.

$\dot{V}O_{2\max}$ is considered the best index of health related physical fitness [19]. $\dot{V}O_{2\max}$ indicates the functional capacity of cardiorespiratory function [15]. According to Rump et al., [20] absolute $\dot{V}O_{2\max}$ relate strongly to the size of the fat free mass, this is logical because it is the oxygen demand of the exercising muscles that decides the oxygen consumption. $\dot{V}O_{2\max}$ are conventional expressed in relation to body mass [2]. Therefore both body mass and body composition of each individual are strongly related to $\dot{V}O_{2\max}$ [20].

The conventional criterion for attainment of $\dot{V}O_{2\max}$ during an exercise test is a plateau in the oxygen uptake despite an increase in intensity [2, 19, 6]. The $\dot{V}\mathrm{O}_2$ plateau phenomenon has been challenged. Several children and adolescents can exercise to exhaustion without demonstrating a $\dot{V}O_{2\max}$ plateau [2, 19]. There are several criteria for reaching $\dot{V}O_{2\max}$. According to Tartaruga et al.,[6] (and the criteria used in the present study) at least, two of the following criteria should be observed: exercising to exhaustion, voluntary request by the subjects, plateau of the oxygen uptake curve, respiratory exchange ratio higher than 1.15, RPE over 18, HF over 190.

2.1 $\dot{V}O_{2\max}$ relative to body mass

An organism with larger body mass has a higher metabolic rate than an organism with a smaller body mass. This is because there is a proportional relationship between mass and metabolism. When the values are normalized by body mass values, larger organisms may present lower physiological values than smaller organisms [6]. Since a person has to carry his own body, body mass is an important determinant of $\dot{V}O_{2\max}$. Excess fat mass relative to fat free mass will increase the workload during exercise but does not contribute to the work performed [21].

When body mass increase, $\dot{V}O_{2\max}$ relative to mass decrease [15]. According to Tartaruga et al., [6] the relationship between $\dot{V}O_{2\max}$ and body mass are strongly related because all exercise requires body movement [6]. The increase in body mass, functional changes of the aerobic system, changes in anaerobic threshold, and changes in running economy may contribute to explain this matter. Numerous studies have focused on various exponential relationships between $\dot{V}O_{2\max}$ and mass and height [2, 1, 17, 10, 22].

Rowland et al [12] and Dencker [7] found that lean body mass (LBM) may explain the differences between genders when expressing $\dot{V}O_{2\max}$. The gender differences are reduced by one half when $\dot{V}O_{2\max}$ are being expressed in relation to LBM instead of total body mass.

Goran et al [9] found that total body fat did not influence $\dot{V}O_{2\max}$, but at the same time obese individuals had a reduced $\dot{V}O_{2\max}$ relative to body mass. This is explained by the fact that $\dot{V}O_{2\max}$ relative to body mass evaluates the ability of an individual to perform exhaustive work. The major influence of body mass on $\dot{V}O_{2\max}$ is explained by fat free mass (FFM); fat mass (FM) does not have any effect on $\dot{V}O_{2\max}$. Fatness and excess body mass do not necessarily imply a reduced $\dot{V}O_{2\max}$, but excess fatness does have a negative effect on submaximal aerobic capacity [9].

2.2 Differences between Boys and Girls

Holsby found [23]that increased $\dot{V}O_{2\max}$ was a result of an increase in age and size. This was supported by Shao [21]. In boys the increase was related most strongly to age and in girls to LBM. At the younger ages it was little difference in $\dot{V}O_{2\max}$ between genders, but as age increased the differences became significant. It has also been shown that at given oxygen uptake girls have a higher heart rate, higher cardiac output, and lower arteriovenous oxygen difference than boys [23].

Armstrong et al [1] found that $\dot{V}O_{2\max}$ for boys were significantly higher than for the girls whether expressed in $l \cdot min^{-1}$or in ratio with body mass $(ml \cdot kg^{-1} \cdot min^{-1})$. Girls $\dot{V}O_{2\max}$ has been significantly associated with stature and mass, while for boys $\dot{V}O_{2\max}$ was significantly correlated with stature, mass and hemoglobin concentration [2, 24].

In younger children there is no difference in hemoglobin concentration and this may not be a reason for gender differences in young children. The differences in $\dot{V}O_{2\max}$ among younger children may be related to variations in body composition since boys have a greater percentage of lean body mass, even in prepubertal years. The differences between boys and girls were reduced when $\dot{V}O_{2\max}$ was related to fat free mass [2].

Results from several studies have shown that in growing children the usual form for expressing $\dot{V}O_{2\max}$ $(ml \cdot kg^{-1} \cdot min^{-1})$ may not be the way to express $\dot{V}O_{2\max}$ [2, 17, 10]. Armstrong and Welsman [2] suggested that throughout the period from prepubertal child to adult $\dot{V}O_{2\max}$ changes in the same way, but the increase in $\dot{V}O_{2\max}$ is less than proportional to the changes in body mass [2, 17].

2.3 Scaling $\dot{V}O_{2\max}$

Metabolic rate, heart rate and many other physiological properties vary with body mass. Metabolic rate is directly attached to the cardiovascular system because of the constant need for oxygen to cells, tissue and muscles [25]. Allometric scaling provides a method for examining the structural and functional consequences of changes in body mass among otherwise similar organisms [26]. The task of allometric scaling is to find a metabolic size which is chosen so that the metabolic rate per unit of body mass is the same for large and small organisms [27].

The conventional method for expressing $\dot{V}O_{2\max}$ as $ml \cdot kg^{-1} \cdot min^{-1}$, in children and adolescents may be incorrect, since growth in children are not regular and different proportions of body segment may occur [5, 2]. The use of allometric scaling may correct for differences in body mass between individuals. Loftin et al [15] suggested that allometric scaling should be considered when comparing $\dot{V}O_{2\max}$ of obese children with normal-weight children.

To be able compare $\dot{V}O_{2\max}$ among individuals with different body mass and body composition, $\dot{V}O_{2\max}$ is usually scaled by dividing the values on body mass ($ml \cdot kg^{-1} \cdot min^{-1}$). Dencker et al[8] found that children defined as obese (according to BMI) had higher absolute values of $\dot{V}O_{2\max}$ ($l \cdot min^{-1}$) and lower $\dot{V}O_{2\max}$ scaled by body mass compared with children of normal body mass. $\dot{V}O_{2\max}$ values of individuals with low body mass may be overestimated, they benefit from their low body mass, and $\dot{V}O_{2\max}$ values may be underestimated for individuals with high body mass, their body mass may be disadvantage for high $\dot{V}O_{2\max}$ values [10].

Through allometric regressions Pettersen et al[5] found that children's and adolescents' $\dot{V}O_{2\max}$ does not increase linear with increasing body mass. Several ways of expressing $\dot{V}O_{2\max}$ have been tried, for example $ml \cdot kg^{-2/3} \cdot min^{-1}$. This is $\dot{V}O_{2\max}$ related to body surface area rather than body weight [5]. Another scaling method for $\dot{V}O_{2\max}$, for children and adolescents are $ml \cdot kg^{-3/4} \cdot min^{-1}$, the benefit with this equation is that this increases significantly with age [14]. There has been noted that when comparing children's $\dot{V}O_{2\max}$ we should use only $2/3$ of their weight ($mass^{2/3}$) [15]. The theory using $2/3$ of individual's body mass is based upon the idea of developing models that will predict how a particular metabolic function changes with body size. The theory using $2/3$ of an individual's body mass is known as the surface law, indicating that oxygen consumption increases as body mass increases [17].

The $2/3$ factor is based on that growth in individuals increases linear with age and that body segment's grow in the same pace, but in humans (and other species) this is not the case. The changes that occur during growth are nonisometric, therefore the $^2/_3$ exponent may not be appropriate to children of all ages [10].

3. Material and Methods

3.1 Design and Study Sample

The present study is based on two different study samples. In a randomized controlled intervention study [28]; obese and overweight children, were referred by general practitioner doctor or public health nurse to an outpatient paediatric clinic. Children living in Oslo aged 3-17 years were examined and enrolled if they were obese according to the Norwegian percentile diagram (body mass above the 97^{th} percentile for height) [28]. The present randomized controlled intervention study included 7-17 year old children with age limitation set due to aerobic fitness measurements. Children could not have medical conditions that could restrict the ability to be physically active or receiving medication that could interfere with growth or weight control. The subjects were randomized in an intervention ($n = 36$) group or control ($n = 24$) group. The intervention and control groups did not differ significantly in maximal oxygen uptake and body composition [28].

Of the 120 subjects invited, 57 with a mean age of 12.1 attended the present study.

In a nested case-control study [29]from the Environment and Childhood Asthma study in Oslo 95 subjects with asthma and 79 subjects without asthma performed maximal running on treadmill with oxygen consumption measured and had the sum of four skinfolds recorded as an estimate of body fat. In the present study 57 subjects from Berntsen et al [28] were included. All subjects were obese and had no other diseases that could affect results. From the study Berntsen et al [29] of 174 subjects, the 79 subjects without asthma were included [29].

The present study was approved by the Medical Ethics Committee and the Data Inspectorate of Norway. Written informed participation consent was obtained from the participating children and their parents.

3.2 Procedures

3.2.1 Anthropometrics

Body mass was measured with the subject wearing light clothes and without shoes to the nearest 0.1kg. Height was measured to the nearest 0.5cm by using a stadiometer. BMI was calculated as body mass (kg) divided by height (m) squared. Body composition was measured through skinfold thickness with a Harpenden fat caliper (Holtain Ltd, Bryberian, UK) or with dual-energy X-ray absorptiometry (DXA, GE-Lunar Prodigy, Madison, WI, USA). The measuring points for skinfold thickness were biceps, triceps, subscapular and suprailiac. With DXA participants were scanned from head to toe in supine position, providing values for bone mineral content (BMC), non-bone lean tissue, fat mass in total body, and fat mass in arms, legs and trunk separately. Skinfold thickness was calculated into fat percentage with the Bray equation [30].

Bray (2001): M and F: Fat (%)=8.71+0.19 subscapular+0.76 biceps+0.18 suprailiac+0.33 triceps

3.2.2 Aerobic Fitness

Aerobic fitness was determined as $\dot{V}O_{2\mathrm{max}}$ during treadmill (Woodway, WI, USA) running was both the incline and speed increased until subjects were exhausted. Heart rate (Polar Vantage, Polar Electro KY, Kempele, Finland) was recorded continuously, and minute ventilation (V_E), respiratory exchange ratio (RER) and $\dot{V}O_{2\mathrm{max}}$ were measured during running using the Sensor Medics, Vmax Spektra (Yorba Linda, CA, USA) or Oxycon Champion (Erich Jaeger GmbH & Co. KG, Hoechberg, Germany) VO2max values were based on the subjective assessment that the children had reached his or her maximal effort, RPE over 18 or reaching RER above 1.00 [28, 29].

3.3 Statistical Analysis

Demographic data are given as mean values and standard deviation (SD) unless otherwise is stated and results as mean with 95% confidence intervals. ANOVA was used to compare physical characteristics and differences between different $\dot{V}O_{2\max}$ values. Body mass and $\dot{V}O_{2\max}$ were log transformed and linear regression were used to find scaling factors for obese and normal weight boys and girls.

The allometric exponent were determined from the logarithmic equation $\log y = b \log x + \log a$, where y is the $\dot{V}O_{2\max}$, x is the mass, a is a constant and b is the allometric exponent. The correlation between children's $\dot{V}O_{2\max}$ and fat percentage were calculated with a bivariate correlation test. Statistical significance was set at $p \leq 0.05$. Statistical analyses were performed with Statistical Package for Social Sciences Version 19.0 (SPSS, Chicago, IL, USA).

4. Discussion of the Methodology

4.1 Design and Study Sample

For the purpose of the present study where the aim was to describe matters on a given time, the cross-sectional design seemed to be most appropriate. In addition to this, the cross-sectional design is fitting for large groups, like the one in the present study [31]. All 136 participants were children or adolescents divided into four groups. As there is an increase in obese people in the population, the 57 obese children in the present study makes a relevant representation of the current population. Since poor $\dot{V}O_{2\max}$ has, in children, been associated with risk factors for cardiovascular diseases [1, 2, 3, 4, 5] it seems appropriate to include children with increased body mass since this seems to influence on the $\dot{V}O_{2\max}$. It seemed appropriate to exclude the children with asthma because they normally use asthma medicine, and this may influence on the actual aerobic capacity.

Since the study attempts to show that there is a difference in how to express $\dot{V}O_{2\max}$ depending on body composition and gender, subjects taking medication regularly and subjects with asthma were excluded from the present study. It is, however, important to note that this may excludes subjects that might have been relevant to represent the current population. A lot of subjects, obese and normal-weight children, use medication that would have excluded them from the study, while their participation might still have been relevant for the results.

The present study attempts to express $\dot{V}O_{2\max}$ in children of different body mass and does not attempt to find a method for increasing the children's

$\dot{V}O_{2\max}$, one the basis of this seems appropriate. In other words the present study takes place in a fixed point in time and not during a longer period where the children are tested several times [32]. Even if the present study design cannot describe cause and effect, the cross-sectional design is able to test covariance between different variables [31].

An alternative study could be to split the children into more groups depending on age for example ages 7-10, 11-13 and 14-17. This would be to show the difference between children, adolescents in pre-puberty stages and adolescents in puberty, considering the scaling factor for $\dot{V}O_{2\max}$.

4.2 Procedures

To be able to determine children's $\dot{V}O_{2\max}$ a treadmill running test was used. The treadmill appears to elicit higher maximal oxygen consumption values than bicycle ergometer. Higher maximal heart rates have also been observed on the treadmill than bicycle. The treadmill is expected to generate the highest aerobic power relative to other exercise modes [39]. This is because running on a treadmill enables subjects to engage a higher percentage of muscular mass than while executing the bicycle ergometer test [33, 39].

Harpenden fat caliper were used to measure skinfold thickness and this estimates the fat percentage. Skinfold thickness is accepted as body fatness predictor because subcutaneous fat can be directly measured with a caliper. As well as its advantages, fat measurements by skinfolds have many drawbacks associated with factors that can affect its accuracy and precision. The use of a standardized methodology increases the reliability of skinfolds thickness measurements [38]. As in the present study, most frequently four skinfolds are measured [36].

DXA measurements scan the whole body to measure bone mineral density (BMD), muscle and fat mass. DXA is one of the most valid methods for analyzing the body composition, for healthy young subjects [37]. The scan is quick, noninvasive and you can see the body composition in a three-screened-off area model [35]. Since the DXA scan may not give the same precision for obese children as for children of normal weight, this may lead to differences in the measurements in the present study. Also because it was the obese children that had been through a DXA scan and the normal weight children had a skinfold thickness measurement of their body composition.

Strengths of the methods: The major strengths of the present study were directs measurements of VO2max and the use of DXA, measureable, except for VO2max test the entire test is quickly done. As mentioned, both DXA and treadmill tests are both accepted as the better alternatives for finding body composition and $\dot{V}O_{2\max}$ [33, 37]. Given this the data returned by these tests should be considered reliable. The validity of the present study is confirmed through the selection of subjects involved as well as to why the excluded subjects were not added to the results [32].

Limitations of the methods: $\dot{V}O_{2\max}$ test is hard, exhausting. Incorrect measurements may occur, because children may not be able to push to exhaustion and they may stop, due to boredom. Harpenden fat caliper were used to measure skinfold thinckness and fat percentage. All the children should have been analyzed through a DXA scan; this would probably have lead to a higher precision when determined the body fat percentage. The fact this wasnât done can result in unreliable results. The use of Borg scale (RPE values) may lead to unreliable results since RPE values are reported perceived exertion[34, 29]. Children may report higher RPE than they should and they feel more exhausted than they actually are, they get bored or they may not able to run to total exhaustion.. The fact that some children were excluded from the present study, the children with asthma and the children that used some type of medicine, may lead to invalid results because the children that were included represents a smaller percentage of the population [32].

4.3 Ethical Considerations

When children are participating in research like the present study, there are ethical issues. The exercise science should not be intimidating, and it can only be ethical if it doesn't places the child at any risk of harm (more than in the daily life), and it is not against his or her own will or interest [2]. Some of the children in the present study were not too comfortable during the $\dot{V}O_{2\max}$ test, but they finished and after a break they would do it again. None of the children were at any risk during the tests, and both the child and their parents had been informed of what the tests would be like and how it would be during the tests. Research that involves children is neither unethical nor illegal as long as the children's interests are taking into consideration[2]. Participating in the present study was voluntary and the children could withdraw at any time.

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Maximal Oxygen Uptake in Children of Different Body Mass

Should maximal oxygen uptake be expressed differently for children of different body mass?

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Abstract

Background: Maximal oxygen uptake ($\dot{V}O_{2\max}$) has important implications for current and future health in children. There is ongoing debate on how to express $\dot{V}O_{2\max}$ in children and adolescents. **Objectives:** Are scaling factors different in obese and normal weight children and between genders? How does percentage fat influence aerobic fitness? **Methods:** 57 obese (30 girls) and 79 children of normal weight (38girls) in the age 7-17 years were include in the present study. $\dot{V}O_{2\max}$ were measured during a treadmill running test, were both the incline and speed increased until subjects were exhausted. Body compositions were measured with dual-energy X-ray absorptiometry (DXA) or a Harpenden fat caliper. Allometric scaling factors were calculated using linear regression of log-transformed data. **Results:** Allometric scaling factors were 0.51 for obese girls, 0.53 for normal weight girls, 0.47 for obese boys and 0.27 for normal weight boys. Obese boys had almost the same allometric scaling factor (0.47) as girls, and normal weight boys (0.27) had the lowest scaling factor of all subjects. **Conclusion:** findings in the present study demonstrate that use of mass exponent when comparing $\dot{V}O_{2\max}$ in obese and normal weight children. It seems that percentage fat doesn't have a great influence on children's $\dot{V}O_{2\max}$. The difference between obese and normal weight children has to be due to other factors than percentage fat.

Key words: allometric scaling, children, maximal oxygen uptake, normal weight, obese

Introduction

The ability to perform aerobic exercise is associated with the individual's maximal oxygen uptake ($\dot{V}O_{2\max}$) [1]. $\dot{V}O_{2\max}$ is the highest rate of consumed oxygen during exercise [2], and it is an important marker for health. Poor $\dot{V}O_{2\max}$ has, in children, been associated with risk factors for cardiovascular diseases [1, 2, 3, 4, 5]. $\dot{V}O_{2\max}$ can be expressed in absolute term $(l \cdot min^{-1})$ or relative to body mass $(ml \cdot kg^{-1} \cdot min^{-1})$ [6].

There seems to be a great difference between boys and girls in $\dot{V}O_{2\max}$. Boys $\dot{V}O_{2\max}$ values are higher than the values of the girls even before puberty [1, 3]. When $\dot{V}O_{2\max}$ is expressed related to body mass, no changes are observed during childhood and adolescents for boys. For girls, though, there is a progressive decline observed in mass-relative $\dot{V}O_{2\max}$ from age 8 [2, 4, 5]. In boys the increase in $\dot{V}O_{2\max}$ with increasing age has been attributed to greater muscle mass and higher hemoglobin concentration. The reason for the decline in girls is less clear, but it seems that this can be explained by the increased fat percentage and body mass [1, 2, 3, 4, 5].

Several researchers have discussed how to express $\dot{V}O_{2\max}$ in children according to different body composition, body mass, and muscle mass and fat mass; although, $\dot{V}O_{2\max}$ relative to body mass is common [3, 7, 8, 9, 10, 11, 12, 13]. It seems to be a disagreement among researchers in how to express $\dot{V}O_{2\max}$ in children. There are several suggestions from several researchers; 0.81 and 0.61 [14], 0.46 [15], 0.68 and 0.37 [10], 0.52 and 0.55 [11], 0.71[4], 0.91 [16] and 0.78 [13]. An agreement among researchers seems to be that $\dot{V}O_{2\max}$ should not be expressed in relation to total body mass. According to Pettersen et al., [17] 0.67 together with 0.75 are the most frequently used exponents when comparing children's $\dot{V}O_{2\max}$.

The study is important because the majority of the earlier done studies haven't included both obese and normal weight children of both genders [3, 7, 8, 13, 18].

The aim of the present study was to determine scaling factors for the relationship between body mass and $\dot{V}O_{2\max}$ and whether these differs between boys and girls, and obese and children of normal weight and how fat percentage influence on $\dot{V}O_{2\max}$.

Material & Methods

Design and Study Sample

The present study is based on two different study samples. In a randomized controlled intervention study [19]; obese and overweight children, were referred by general practitioner doctor or public health nurse to an outpatient paediatric clinic. Children living in Oslo aged 3-17 years were examined and enrolled if they were obese according to the Norwegian percentile diagram (body mass above the 97^{th} percentile for height) [19]. The present randomized controlled intervention study included 7-17 year old children with age limitation set due to aerobic fitness measurements. Children could not have medical conditions that could restrict the ability to be physically active or receiving medication that could interfere with growth or weight control. The subjects were randomized in an intervention ($n = 36$) group or control ($n = 24$) group. The intervention and control groups did not differ significantly in maximal oxygen uptake and body composition [19].

Of the 120 subjects invited, 57 with a mean age of 12.1 attended the present study.

In a nested case-control study [20]from the Environment and Childhood

Asthma study in Oslo 95 subjects with asthma and 79 subjects without asthma performed maximal running on treadmill with oxygen consumption measured and had the sum of four skinfolds recorded as an estimate of body fat. In the present study 57 subjects from Berntsen et al [19] were included. All subjects were obese and had no other diseases that could affect results. From the study Berntsen et al [20] of 174 subjects, the 79 subjects without asthma were included [20].

The present study was approved by the Medical Ethics Committee and the Data Inspectorate of Norway. Written informed participation consent was obtained from the participating children and their parents.

Procedures

Anthropometrics

Body mass was measured with the subject wearing light clothes and without shoes to the nearest 0.1kg. Height was measured to the nearest 0.5cm by using a stadiometer. BMI was calculated as body mass (kg) divided by height (m) squared. Body composition was measured through skinfold thickness with a Harpenden fat caliper (Holtain Ltd, Bryberian, UK) or with dual-energy X-ray absorptiometry (DXA, GE-Lunar Prodigy, Madison, WI, USA). The measuring points for skinfold thickness were biceps, triceps, subscapular and suprailiac. With DXA participants were scanned from head to toe in supine position, providing values for bone mineral content (BMC), non-bone lean tissue, fat mass in total body, and fat mass in arms, legs and trunk separately. Skinfold thickness was calculated into fat percentage with the Bray equation [21].

Bray (2001): M and F: Fat (%)=8.71+0.19 subscapular+0.76 biceps+0.18 suprailiac+0.33 triceps

Aerobic Fitness

Aerobic fitness was determined as $\dot{V}O_{2\max}$ during treadmill (Woodway, WI, USA) running was both the incline and speed increased until subjects were exhausted. Heart rate (Polar Vantage, Polar Electro KY, Kempele, Finland) was recorded continuously, and minute ventilation (V_E), respiratory exchange ratio (RER) and $\dot{V}O_{2\max}$ were measured during running using the Sensor Medics, Vmax Spektra (Yorba Linda, CA, USA) or Oxycon Champion (Erich Jaeger GmbH & Co. KG, Hoechberg, Germany) VO2max values were based on the subjective assessment that the children had reached his or her maximal effort, RPE over 18 or reaching RER above 1.00 [19, 20].

Statistical Analysis

Demographic data are given as mean values and standard deviation (SD) unless otherwise is stated and results as mean with 95% confidence intervals. ANOVA was used to compare physical characteristics and differences between different $\dot{V}O_{2\max}$ values. Body mass and $\dot{V}O_{2\max}$ were log transformed and linear regression were used to find scaling factors for obese and normal weight boys and girls.

The allometric exponent were determined from the logarithmic equation $\log y = b \log x + \log a$, where y is the $\dot{V}O_{2\max}$, x is the mass, a is a constant and b is the allometric exponent. The correlation between children's $\dot{V}O_{2\max}$ and fat percentage were calculated with a bivariate correlation test. Statistical significance was set at $p \leq 0.05$. Statistical analyses were performed with Statistical Package for Social Sciences Version 19.0 (SPSS, Chicago, IL, USA).

Results

Physical characteristics are shown in table 1. There were no significant differences in the children's age and height ($P = 0.445$ and $P = 0.635$ respectively). The normal weight subjects were the oldest and also the subjects with the lowest body mass. The fat percentage differs between the groups and between genders. In both obese and normal weight subjects the girls had the highest percentage of fat. Both body mass and fat percentage were significant different between the children ($P = 0.002$ and $P < 0.0001$).

Cardiorespiratory parameters are shown in table 2. $\dot{V}O_{2\max}$ ($l \cdot min^{-1}$) showed no significant differences between the children ($P = 0.409$). $\dot{V}O_{2\max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) showed that the normal-weight subjects were the ones with the highest values, and the no significant difference between the children ($P = 0.846$). Normal weight boys were the subjects that had the absolute highest $\dot{V}O_{2\max}$, in both measurements. Normal weight boys had the highest HRmax values and obese boys had the lowest. There were no significant differences between the children in HRmax ($P = 0.269$) and RPE($P = 0.439$).

The association between body mass and $\dot{V}O_{2\max}$ in obese and normal weight boys and girls are shown in figure 1 and 2. The mass exponent for normal weight boys were 0.27, for obese boys 0.47, for normal weight girls

0.53 and for obese girls 0.51. Table 3 illustrates the differences in $\dot{V}O_{2\max}$ between children when expressed with different mass exponent. Normal weight children had the highest values when expressed with the factors 0.67 and 0.75. $\dot{V}O_{2\max}$ expressed with the mass exponent found in the present study, normal weight boys reach the highest and normal weight girls had the lowest values. There were no significant differences between different mass exponents, between the children, found in the present study (P values from 0.372-0.884).

The correlation between fat percentage and $\dot{V}O_{2\max}$ in the children are -0.106 with a P value of 0.36 and the shared variance of 0.01. Only 1% of the $\dot{V}O_{2\max}$ in children is explained by variation in fat percentage.

Discussion

The objectives of the present study were to determine whether is mass exponent differ between obese and normal weight children of both genders, and how fat percentage influence on $\dot{V}O_{2\max}$.

The major findings in the present study were the different mass exponent between genders of different body mass and that fat percentage only has a small influence on the children's $\dot{V}O_{2\max}$. The mass exponents that were found were for boys of normal weight 0.27 were the lowest exponent found, obese boys 0.47, and girls of normal weight 0.53 the highest exponent found and obese girls 0.51. There was only 1% of the variation in $\dot{V}O_{2\max}$ of the children that was explained by the variation in fat percentage.

Higher mass exponents are reported for normal weight boys in the majority of the studies than in the present study; 1.01 [14], 1.10, 0.91[16] 7-15 year old, 0.71[4], 0.78 [13] (common for both obese and normal weight children), 0.65 (both genders together) [1], 0.75 (for 8-9 year old boys) [17], the mass exponent that were closest to which found in the present study was 0.37 [10] and 0.71 (both genders together) [3].

The mass exponents found for girls in the present study are more similar to what reported by others. Loftin et al [15] found an exponent of 0.46 in obese and normal weight girls. Rowland [12, 22, 11] found a mass exponent of 0.55 in 12 year old girls (mean age 11.7-, 12.2- and 11.7 years), 0.68 was found by Rogers et al. [10] and 0.61 was found by Eisemann et al., [14]. The mass exponents found for both genders together are also more similar to the findings in the present study in girls, than normal weight boys. The mass exponents found by Rowland [12], Eisenmann [14] and Loftin [15] were the ones that were most similar to what found in the present study.

The main used exponents when expressing $\dot{V}O_{2\max}$ in accordance to body mass are 0.67 and 0.75 [4, 5, 10, 14, 15, 17], for both boys and girls combined. This is higher than in the present study were we have stratified on both gender and whether the children were obese or not. These two mass exponents are the same for both boys and girls and no matter what body mass.

The reason for all the different mass exponents found between children of different gender and body mass, may be due to different fat percentage of the children. Girls tend to have higher fat percentage than boys, as in the present study, this may be the reason for the differences between genders. Since the obese children also have higher percentage fat, this might to seem have an influence on $\dot{V}O_{2\max}$ values. Though according to Goran et al [9] fat mass (FM) don't influence on $\dot{V}O_{2\max}$ in children, and fat mass and $\dot{V}O_{2\max}$ values should be considered independent variables.

The findings in the present study seems to correlate with the findings in the study by Goran [9]. A correlation test showed only an $r = 0.106$ and a shared variance of 11%. This means that the different $\dot{V}O_{2\max}$ values and mass exponent between obese and normal weight children must be influenced by other factors than FM. The differences might be due to increased body mass in obese children and other factors like hemoglobin concentration and hormones [2]. It seems that FM and $\dot{V}O_{2\max}$ should be considered independent from each other. Goran [9] concluded that FM and excess body mass don't necessarily imply a reduced $\dot{V}O_{2\max}$, but excess FM does have a strong effect on the submaximal $\dot{V}O_{2\max}$. In conclusion the findings in the present study demonstrate that use of mass exponent when comparing $\dot{V}O_{2\max}$ in obese and normal weight children. There was found different mass exponent for the children in the present study. It seems that when expressing or comparing $\dot{V}O_{2\max}$ between children a mass exponent should be used. The findings illustrate that fat percentage and $\dot{V}O_{2\max}$ doesn't have a strong correlation, fat percentage does not have a great influence on the $\dot{V}O_{2\max}$ of children of different genders.

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Appendix A. Tables and Figures

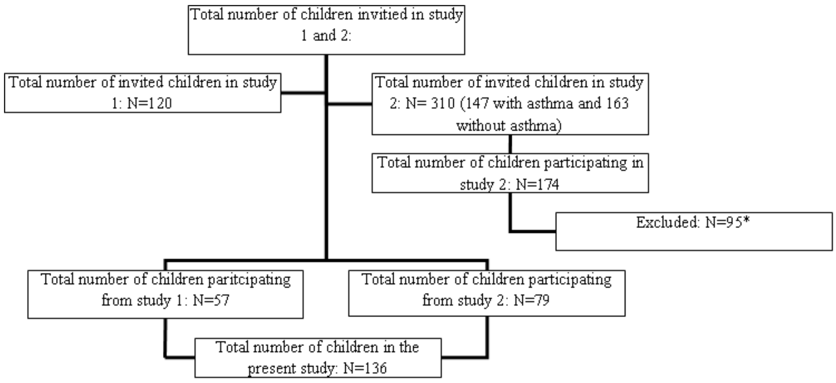

Figure 1: Flowchart showing inclusion and exclusion of participants in the study and classification of the participating sample. *Children with asthma were excluded.

Table 1: Descriptive data of the participating children. Data are given as mean and standard deviation (SD) unless otherwise stated*.

	Obese		Normalweight		P
	Girls (n=30)	Boys (n=27)	Girls (n=38)	Boys (n=41)	
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	
Age (years) *Mean (min-max)**	11.7 (7.7-16.5)	12.7 (9.7-17.2)	13.5(12.6-14.1)	13.6(12.6-14.3)	0.445
Body mass (kg)	73.2 (19.8)	77.3 (20.7)	49.1 (7.8)	51.7 (11.1)	0.002
Height (cm)	154 (11)	161 (12)	161 (6)	163 (8)	0.635
Percentage fat(%)	48.6 (5)	44.3 (5.7)	21.8 (3.9)	20.1 (5)	<0.001

Table 2: Data from exercise test of the participating children. Data are given as mean and confidens interval.

	Obese				Normalweight				P
	Girls (n=30)		Boys(n=27)		Girls (n=38)		Boys(n=41)		
	Mean	Confidens interval	Mean	Confidens interval	Mean	Confidens interval	Mean	Confidens interval	
VE max (l/min)	83.8	(47.5-148.9)	86.0	(52.2-147.4)	87.1	(54.3-111.9)	99.1	(64.4-138.5)	0.259
RER	1.06	(0.91-1.18)	1.02	(0.89-1.22)	1.09	(0.9-1.24)	1.05	(0.97-1.15)	0.016
VO2max(l/min)	2.42	(1.30-3.91)	2.60	(1.49-3.59)	2.41	(1.64-2.97)	2.90	(1.81-4.29)	0.409
VO2max(ml/kg/min)	33.2	(21.0-41.2)	34.4	(23.2-45.8)	49.3	(33.9-62.1)	57.0	(33-73)	0.846
HRmax (beat/min)	193	(172-208)	191	(170-215)	195	(172-210)	196	(180-213)	0.269
Borg (RPE)	18	(13-20)	18	(16-20)	18	(17-20)	18	(15-20)	0.439

Table 3: Shows differences in VO2max and VO2max with different scaling factors, including scaling factors found in the present study, between genders and subjects with different body compositions.

	Obese				Normal weight				P
	Girls (n=30)		Boys(n=27)		Girls (n=38)		Boys (n=41)		
	Mean	Confidens Interval	Mean	Confidens Interval	Mean	Confidens Interval	Mean	Confidens Interval	
mlxkg$^{0.67}$min	136	(158-173)	142	(188-215)	163	(135-157)	207	(155-181)	0.856
mlxkg$^{0.72}$min	96	(114-125)	101	(136-157)	120	(97-113)	151	(111-131)	0.735
mlxkg$^{0.51}$min	270	(304-331)	284	(354-403)	305	(262-305)	389	(303-348)	0.843
mlxkg$^{0.47}$min	320	(357-389)	338	(415-472)	356	(310-360)	455	(359-411)	0.760
mlxkg$^{0.38}$min	247	(280-305)	261	(327-372)	282	(241-280)	360	(279-321)	0.884
mlxkg $^{0.27}$min	756	(808-878)	803	(915-1043)	775	(710-829)	921	(830-938)	0.372
mlxkgxmin	33.2	(21.0-41.2)	34.4	(23.2-45.8)	49.3	(33.9-62.1)	57.0	(33-73)	0.846
L/min	2.42	(1.30-3.91)	2.60	(1.49-3.59)	2.41	(1.64-2.97)	2.90	(1.81-4.29)	0.409

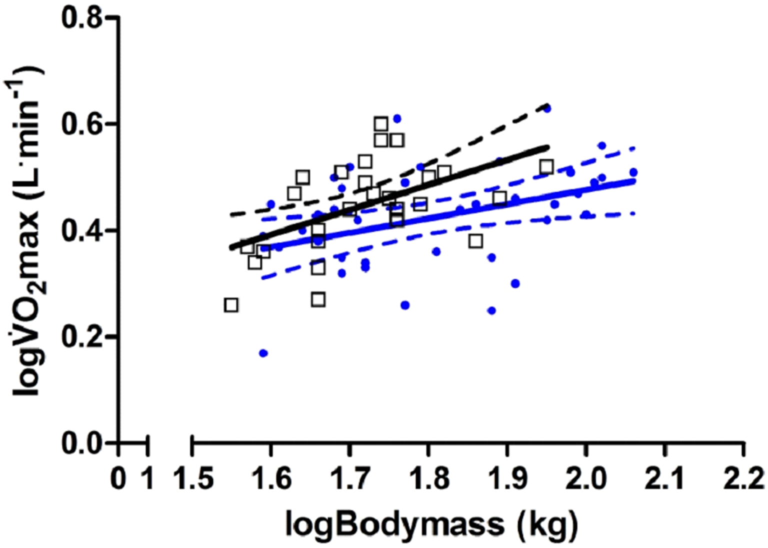

Figure 2: Correlation between body mass and VO2max in boys. Colored dots are normal weight boys, squares are obese boys.

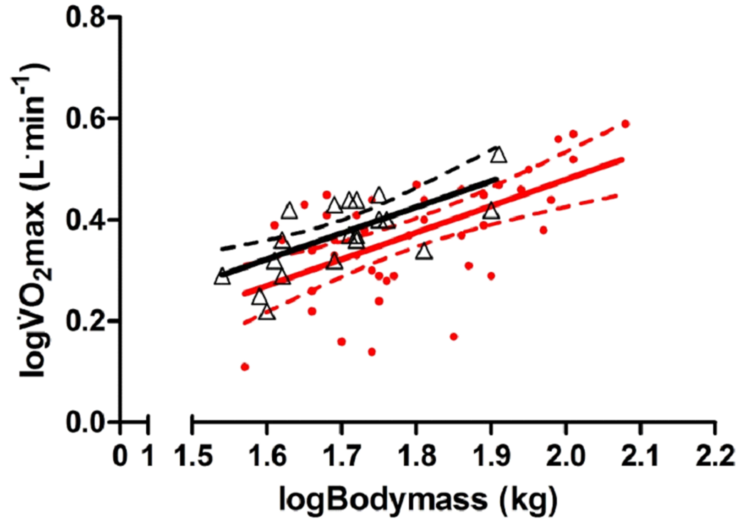

Figure 3: Correlation between body mass and VO2max in girls. Colored dots are normal weight girls, and triangles are obese girls.