THE EUROPEAN SOCIETY OF MEDICINE
Medical Research Archives, Volume 12 Issue 11

RESEARCH ARTICLE

Sex Differences in Maturity Offset, Peak Height Velocity, and Cardiorespiratory Fitness Among Overweight Children Nearing Adolescence

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OPEN ACCESS

PUBLISHED
30 November 2024

CITATION
Kaur, A., et al., 2024. Sex Differences in Maturity Offset, Peak Height Velocity, and Cardiorespiratory Fitness Among Overweight Children Nearing Adolescence. Medical Research Archives, [online] 12(11). https://doi.org/10.18103/mra.v12i11.5400

DOI
https://doi.org/10.18103/mra.v12i11.5400

ISSN
2375-1924

ABSTRACT

Purpose of the study: The study aimed to assess maturity offset in overweight children nearing adolescence and investigate potential differences in peak height velocity and fitness levels within this population.

Methodology: The study involved 28 individuals (14 boys and 14 girls) aged 8-11 years with a body mass index >85th percentile. Maturity offset, peak height velocity, and cardiovascular fitness were measured for all subjects.

Results: The study revealed that the average age of peak height velocity for girls was 10.69 ± 2.51 years, while for boys it was 13.40 ± 2.29 years. Differences were observed in age of peak height velocity, maturity offset, leg length, and cardiorespiratory fitness, with girls having higher means for the maturity offset and leg length and boys having higher means for peak height velocity and cardiorespiratory fitness.

Conclusions: In late childhood, boys with an elevated body mass index have higher cardiorespiratory fitness as compared to girls. Girls who are overweight tend to reach maturity earlier than boys with a similar body mass index. Additionally, girls experience an early growth spurt in terms of height compared to boys, although boys demonstrate a superior overall peak height gain compared to girls.

Keywords: **Late** childhood, Overweight, Maturity offset, Peak height velocity, Fitness.

Abbreviations: **BMI**- Body Mass Index, **PHV**- Peak High Velocity, **VO_2 max** - Maximal oxygen consumption

Introduction

Childhood obesity rates have been steadily increasing in the United States for more than a decade, which is a concerning trend as it negatively impacts the physical health of young children in the country. According to data collected by the National Center for Health Statistics (NCHS) between 2017 and 2020, the prevalence of obesity among children aged 6 to 11 years is estimated to be 20.7%, while it increases to 22.2% among those aged 12 to 19 years.[1]

There are several factors that contribute to the rise in childhood obesity, but one of the major causes is the lack of physical activity. Studies have shown that lower levels of physical activity are linked to decreased functional exercise capacity in children.[2,3,4] Furthermore, cardiorespiratory fitness, which is measured by VO_2max max, has a direct relationship with cardiovascular risk and adiposity in children with obesity. The strength of children may also be affected by cardiovascular fitness and obesity. Handgrip strength testing has shown a strong positive correlation with predicted VO2 max and a weak negative correlation with fat mass.[5,6]

Assessing maturity is an essential aspect of youth sports stratification, research purposes, and athletic development. It helps examine individuals in late childhood and control for differences in maturity. Predicted maturity offset, which is the time before peak height velocity (PHV), is now widely used as an indicator of maturity status in studies of physical activity, fitness, and sports.[7,8] Maturity offset refers to the time difference between a child's chronological age and their biological age at peak height velocity. PHV is the period during puberty when individuals experience their maximum growth rate in stature. [9] This is typically the fastest period of growth in terms of height. Predictive models based on factors like chronological age, height, and weight are used to calculate maturity offset.[10] By estimating maturity offset, researchers and healthcare professionals can assess an individual's biological maturity relative to their peers. Coaches can also use this knowledge to design effective training programs that optimize the athletic development of children.[11]

Multiple studies have found a correlation between adiposity (body fat) and obesity, which can affect the timing of puberty.[12] The literature suggests that girls with a higher body mass index (BMI) tend to experience puberty earlier than boys. One proposed mechanism for this is that overweight children have higher levels of leptin, which may contribute to earlier puberty.[13] Additionally, increased adiposity might impact hormone levels during growth, which could further influence the timing of maturation.[14,15]

It is important to mention that the current research on the timing of puberty, maturity offset, and peak height velocity (PHV) has largely focused on children and adolescents with normal BMI[9,16] However, there is a significant lack of research on the same topics for overweight and obese children, particularly those who are approaching adolescence. This issue is relevant due to the high prevalence of childhood obesity in the United States and the decreasing levels of physical activity in this population.

The purpose of this study was to identify the age of PHV in overweight children nearing adolescence and to examine if there is a difference in maturity offset and age at PHV across sex within the group. It was hypothesized that there would be a sex difference in the age of PHV and that girls will have a younger age at PHV. Additionally, this study explored if there is a difference in the fitness levels of the age-matched adolescents who are overweight.

Methods

SUBJECTS

The study received approval from the Institutional Review Board Committee (Approval number 30821). Written consent was obtained from all individual participants and parents. A total of twenty-eight individuals between the ages of 8-11 years were included in this study, consisting of 14 boys and 14 girls. These participants were selected using a convenience sampling method and had BMI scores above the 85th percentile for their age. Based on preliminary data, it was determined that a sample size of 26 subjects was needed to achieve 80% power for detecting significant correlations. Subjects with musculoskeletal injuries, a history of child abuse, neurological deficits, or cardiopulmonary issues were excluded from the study.

DATA COLLECTION

The data collection was done in a gait analysis movement lab in the state university. The data collection was divided into two visits. On the first visit, anthropometric characteristics including chronological age, height, sitting height, weight, waist circumference, and hip circumference were collected by a single clinician. The height was measured after a deep inhalation while standing fully erect against a wall, with the participant's feet together. Sitting height was measured as the distance between the seated surface and the top of the head while sitting erect. Leg length (sub ischial) was estimated by subtracting the sitting height from the standing height. Waist girth was measured midway between the lower margin of the ribcage and the iliac crests. Hip girth was measured around the buttocks to estimate the maximum circumference using a tape measure (Gulick II, Country Technology Inc., Gays Mills, WI). Waist girth (cm) was divided by hip girth (cm) to derive the waist to hip ratio (WHR). The Body Mass Index was calculated as the participant's weight (kg) divided by the standing height (m^2).[17] Measure of adiposity, or % body fat, was acquired via whole body air-displacement plethysmography (Bod Pod; Life Measurement Instruments, Concord, CA).

Maturity offset was estimated using sex specific algorithms derived by Mirwald et al.

Maturity offset for boys= −9.236+(0.0002708 * (Leg Length * Sitting Height)) + (−0.001663 * (Age * Leg Length)) + (0.007216 * (Age * Sitting Height)) + (0.02292 * (Weight/Height * 100)), with R = 0.94, R^2 = 0.89, and SEE = 0.59.

Maturity offset for girls= −9.376 + (0.0001882 * (Leg Length * Sitting Height)) + (0.0022 * (Age * Leg Length)) + (0.005841 * (Age * Sitting Height)) – (0.002658 * (Age * Weight)) + (0.07693 * (Weight/ Height * 100)), with R = 0.94, R^2 = 0.89, and SEE = 0.56.

Finally, the age of PHV was calculated by adding the maturity offset to the chronological age.[10] During the first visit, VO_2max was estimated using the Nemeth submaximal treadmill walking protocol[5], which has been shown to be valid and reliable in 130 overweight and obese children. Subjects walked on the treadmill at a brisk, but comfortable, velocity for four minutes on a level (0% grade) surface and four minutes at 5% grade. Heart rate and perceived exertion, Wong-Baker Face Pain Scale, were monitored every two minutes. Heart rate documented prior to walking (at rest) and at the end of the four minutes, in combination with walking speed, was used to calculate an estimated VO_2 max to predict fitness level. Cardiorespiratory fitness was estimated by the Nemeth Protocol[29] as follows:

VO_2max = -1772.81 + 318.64 * Sex (F= 0, M= 1) + 18.34 * Weight (kg) + 24.45 * Height (cm) - 8.74 × 4 min HR - 0.15 Weight (kg) *HR difference + 4.41 * Speed (mph) * HR difference.

On the second visit, Cardiovascular fitness, defined as the estimated maximal aerobic capacity (VO_2 max), was measured using the Progressive Aerobic Cardiovascular Endurance Run (PACER) protocol. The protocol required subjects to move between two markers, placed 15 m apart, within a progressively decreasing time interval. The activity was terminated if the subject failed to reach the 15 m marker in the allotted time twice or could no longer maintain the required speed. Physical fitness was estimated using a Quadratic Model[28]:

$$VO_2 \text{ max} = 0.49 * (PACER_{LAPS}) - 0.0029 * (PACER_{LAPS})^2 - 0.62 *(BMI) + 0.35 *(Age * Gender) + 41.77.$$

Progressive Aerobic Cardiovascular Endurance Run (PACER) is often completed by groups of students simultaneously; a research team member completed the PACER with each subject. This strategy was used to reduce any embarrassment the subject might feel by being observed by researchers as well as to provide motivation for the subject to provide maximal effort. The subjects also completed a Nemeth protocol to estimate cardiorespiratory fitness.

STATISTICAL ANALYSIS

Descriptive statistics were computed for all variables, and the normality of their distribution was assessed using the Shapiro-Wilk test. Except for sitting height and relative VO_2max, all variables displayed a normal distribution. Between-group comparisons were conducted using a Mann-Whitney U test for the two non-parametric variables. To analyze the differences between the two groups based on sex, an independent t-test was conducted for each variable. A significance level of less than 0.05 was used to determine the statistical significance of the data. Data were graphically displayed, and correlation coefficients and regression models were used to compare two methods of $V0_2$ estimation. All data analysis was performed using IBM Statistical Package for the Social Sciences, Version 26 (IBM Corp., Armonk, NY).

Results

SUBJECT CHARACTERISTICS

Twenty-eight participants (14 boys, 14 girls) between the ages of 8-11 years completed the study. The average age of the participants was 10.19 years, with an average height of 148.25 cm and an average weight of 58.74 kg. Descriptive statistics for all participants are listed in Table 1.

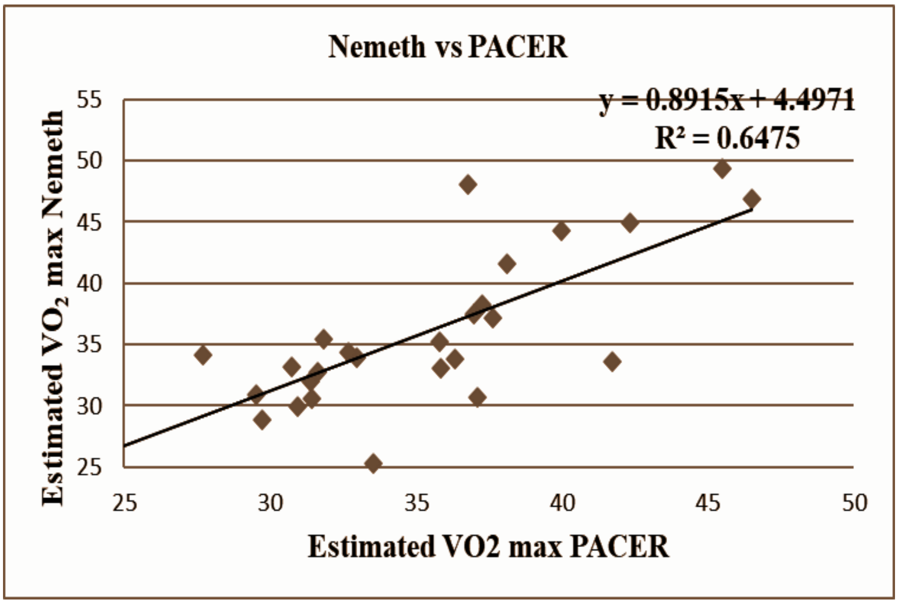
The mean age of PHV for girls was 10.69 ± 2.51 years, and the mean age of PHV for boys was 13.40 ± 2.29 years. No significant differences were seen in weight, height, and BMI (Table 2).

There was a strong association between the two methods of VO_2max estimation, Estimated by Nemeth protocol and PACER protocol (Figure 1). The Nemeth Protocol was used for further analysis.

Additionally, there were significant differences in age of PHV ($t = -2.97$, $p = .006$), maturity offset ($t = -4.253$, $p = .000$), and leg length ($t = 2.59$, $p = .015$) between boys and girls. For all three of these variables, girls had higher means. All other variables used in the for maturity offset demonstrated non-significant differences (Table 3).

Statistically significant sex differences were reported between two measures of cardiovascular fitness VO_2max ($t = 2.58$, $p = 0.16$) and PACER VO_2max ($t = 2.435$, $p = 0.15$). In both cases, boys demonstrated a higher level of cardiovascular fitness (Table 3).

Figure 1: Showing a positive relationship between VO_2 max estimated by Nemeth and PACER.



There was a strong association between two methods of VO_2max estimation (Figure 1).

No significant differences were seen in weight, height, and BMI (Table 2). Statistically significant sex differences were reported between two measures of cardiovascular fitness VO_2max ($t = 2.58$, $p = 0.16$) and relative VO_2max ($t = 2.435$, $p = 0.15$). In both cases, boys demonstrated a higher level of cardiovascular fitness (Table 3).

Table 1. Descriptive characteristics and anthropometric measures of the subjects (n=28)

	Mean ± SD
Age (y)	10.19 ± 1.00
Height (cm)	148.25 ±8.67
Weight (kg)	58.74 ± 14.9
BMI (kg/m^2)	26.89 ± 5.45
Leg Length (cm)	82.55 ± 9.18
Seated Height (cm)	113.67 ± 11.71
VO_2max (mL/min)	2037.71 ± 377.79
Relative VO_2max (mL/min/kg)	35.62 ± 6.54

Table 2. Age matched comparison between the groups

Variable	Girls	Boys	mean difference	95% confidence interval		P-value
				lower	upper	
Age (y)	10.31 ± .97	10.07 ± 1.05	-.239	-1.027	.549	0.538
BMI (kg/m^2)	26.7± 5.63	27.0 ± 5.28	.224	-4.093	4.543	0.916
Height (m)	1.48 ± 0.1	1.49 ± 0.08	-.071	-6.935	6.793	0.983
Weight (kg)	59.32 ± 17.1	61.4 ± 17.8	-1.144	-12.933	10.645	0.84

*Significant P value = /<0.05

Figure 2- Showing visual comparisons between the groups for leg length, age at PHV, maturity offset and $V0_2$ max.

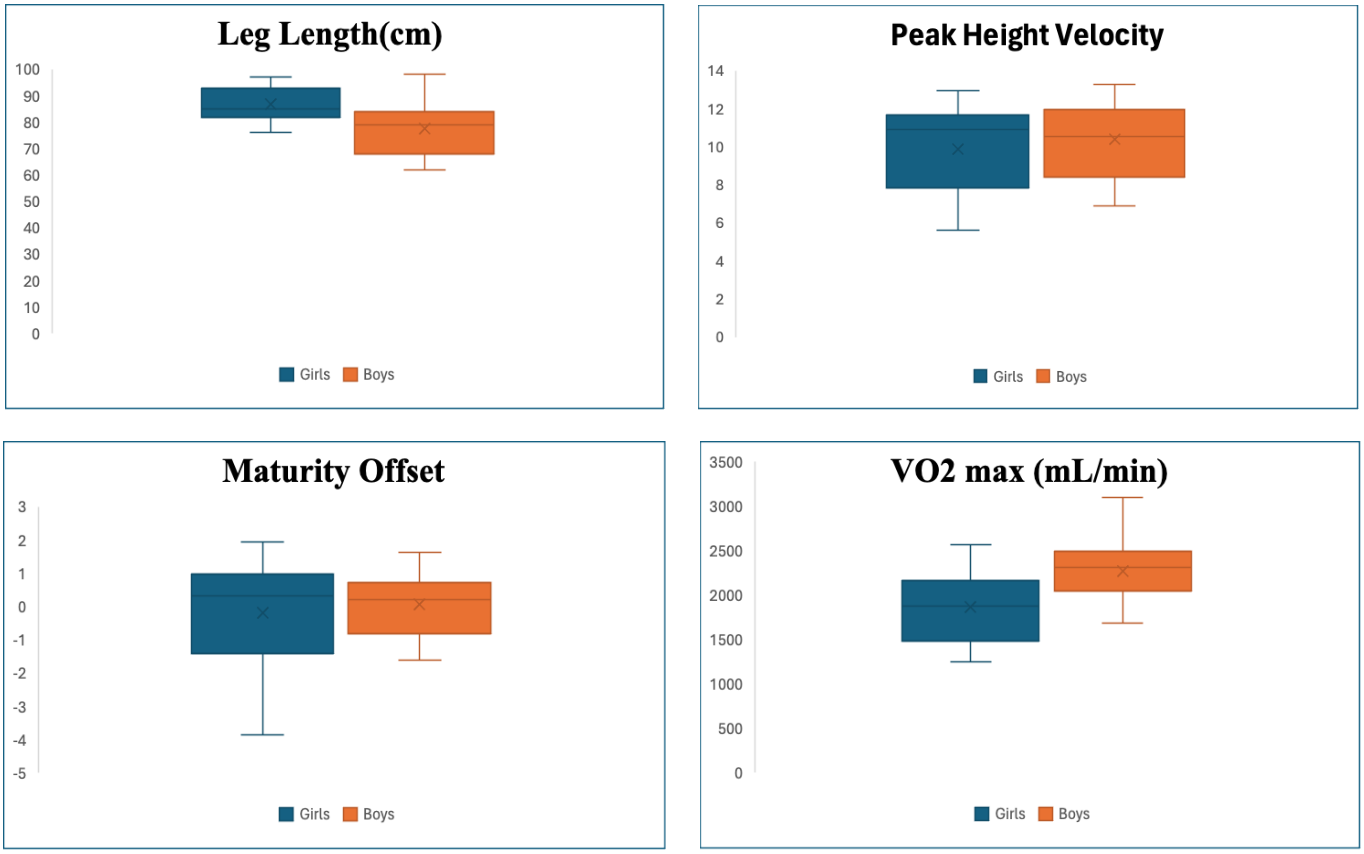


Table 3- Age matched comparisons between the groups for leg length, age at PHV, maturity offset and V02 max.

Variable	Girls	Boys	mean difference	95% confidence interval		P-value
				lower	upper	
Leg Length(cm)	86.64+6.33	78.46 +9.94	-8.178	-14.656	-1.700	0.01*
Age at PHV (y)	10.69 ± 2.51	13.40 ± 2.29	-2.712	-4.585	-.840	0.006*
Maturity offset	3.08. ± 1.08	0.61. ± 1.71	-2.475	-3.671	-1.278	0.000*
VO2 max(ml/min)	1869.77 ± 392.61	2205.64 ± 285.57	335.867	67.919	603.81	0.016*

*Significant P value = /<0.05

Discussion

The current study involved boys and girls aged 8-11 years, with BMI values above the 85th percentile. The study sought to evaluate maturity offset, age of PHV in individuals in late childhood who are overweight, and to determine whether greater adiposity would have sex-wise differences with PHV, maturity offset, leg length, and cardiorespiratory fitness levels. The subjects' height and mass were similar for both males and females for their specific age group. Previous literature has compared boys and girls, and girls had significantly greater BMI, waist circumference, and subcutaneous fat. Generally, it is common for females to carry higher BMI values than their male counterparts. This has been a consistent finding amongst adults and children.

We found that leg length measurement was higher in girls compared to boys for the age group of 8-11 years, with a mean difference of 8.17. Our findings partially supported our hypothesis that girls that are overweight or obese will have early maturation, which is consistent with studies[14,15] that obesity is associated with earlier maturation in girls. It is well suggested that critical body weight triggers menarche, which in turn causes an increase in the metabolic rate that affects the hypothalamic-ovarian feedback, decreasing the sensitivity of estrogen.[18] This critical weight is attained earlier in children that are overweight and obese, hence causing early maturation. Previous literature has also suggested increased body fat is often seen with an early height spurt in puberty when sex comparison is made. As girls mature earlier than boys, they show an earlier height spurt in comparison. Otherwise, boys demonstrate a greater peak height gain overall when compared to girls.[19]

Our second hypothesis that cardiorespiratory fitness is better in boys that are overweight vs. girls that are overweight was supported by our findings. We found a higher VO2 max in boys that are overweight as compared to the girls. Pojskic et al., in their study, found that girls had lower physical activity levels and cardiorespiratory fitness across all the age groups.[20] Another study by Ekelund et al found that physical activity was inversely proportional to fat mass in boys, and not in girls.[21] Overall, in the literature, diverse explanations explain why boys with obesity have a higher absolute VO2 max when compared to girls or children who are not obese. Increased total body mass can lead to higher absolute VO2max in individuals that are overweight and especially in children with obesity.[4-6]

There are multiple reasons why girls might have a lower VO2 max than boys. One possible reason could be linked to physiology. Obesity can cause hyperandrogenemia, which is when there are high levels of male hormones in the body. This can lead to the production of cytokines and adipokines, which can stimulate adrenal synthesis. This, in turn, can lead to hyperandrogenemia and central obesity. Increasing adiposity and hormonal changes are associated with lower skeletal muscle oxidative capacity and capillarization in girls.[22] In addition, men and women have different VO2 max levels due to differences in their body compositions and hemoglobin levels. Men typically have higher hemoglobin levels than women, which allows for greater blood transport capacity and better oxygen intake during training. As a result, men generally have higher aerobic capacities than women. Women, on the other hand, tend to have lower VO2 max levels due to their higher percentage of body fat and lower oxygen transport.[23] Moreover, Berndtsson et al. have mentioned that aerobic activities like swimming, rowing, paddling, etc., will result in a greater increase in absolute VO2 max versus more weight-dependent activities like running, walking, stair climbing, etc., which will yield a lower VO2 max increase. This information can be vital for coaches and parents of children that are overweight to select the appropriate activities.[24]

Our third finding reveals variability in the timing of puberty related growth spurts (PHV). The study found that girls attain PHV earlier than boys and there is a significant difference between the two groups. Additionally, our findings show that girls have a higher maturity offset than boys, with a substantial difference. A study by Glass et al. found that girls with obesity have a significantly younger estimated age of PHV (mean ± SD = 11.1 ± 0.5 years) when compared to boys (mean ± SD = 13.3 ± 0.7 years).[25] This suggests that the higher metabolism, accumulation, and distribution of adipose tissue in girls can lead to increased estrogen production, which may stimulate the onset of puberty and PHV. This could be the biological mechanism behind the association between adiposity and early maturation in girls. On the other hand, males may have late maturity due to increased estrogen levels, which result in a relative hypogonadotropic mechanism and reduced levels of testosterone.[25,26,27]

Conclusion

The conclusions drawn from this study suggest that boys who are overweight or obese exhibit a higher VO2 max compared to girls. It is crucial to recognize the potential risks associated with reduced physical activity and musculoskeletal injuries in children and adolescents, particularly among girls with obesity. Considering the health risk factors associated with obesity, it is imperative to encourage children with obesity to engage in activities that promote fitness and mitigate the risk of metabolic syndrome in adulthood.

It is important to acknowledge the limitations of this study, which include several factors that should be taken into consideration when interpreting the results. The study had a small sample size and a narrow age range, thus limiting the generalizability of the findings to all children and adolescents. Additionally, the absence of separate categories for children with obesity and children who are overweight may have hindered the attainment of more precise and accurate results. Unfortunately, due to the small size, this categorization was not feasible. Despite these limitations, this study contributes to the existing literature by examining the PHV, maturity offset, and VO2 max in boys and girls who are overweight, which is a relatively understudied area.

To gain a comprehensive understanding of PHV and maturity offset, it is recommended that further longitudinal studies be conducted. Additionally, the influence of ethnicity/race should be considered as an essential factor when investigating obesity and maturation. Furthermore, conducting studies on physical activity and sports interventions among children who are overweight or obese and comparing them to children with a normal BMI, would provide valuable insights into the optimal timing and type of aerobic activities that best suit this population, ultimately enhancing their fitness levels.

Conflicts of Interest:

All authors declare that they have no conflicts of interest.

Funding Statement:

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sector.

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