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Indicators of aerobic capacity

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Abstract
Purpose: Secular trends related to height (plateauing) and weight (increasing) indicates a need for current data related to children's aerobic capacity.
Methods: In the present study, biological indicators (age, sex, Body Mass Index, and maturation) of aerobic capacity were examined in children ages 6-16. All children were tested on the Progressive Aerobic Cardiovascular Endurance Run (PACER) during regular physical education class.
Results: Results indicate that body mass, age, sex and maturation all contributed to PACER performance and, thus, aerobic capacity. As hypothesized, chronological age was positively correlated with PACER score. In terms of sex differences, at age sixteen, both boys and girls recorded their highest respective mean PACER scores, with girls at 38.04, 20-meter lengths and boys achieving 65.43 lengths.
Conclusion: Regardless of sex differences, as BMI increased, PACER scores dropped. In the present study, maturation offset had a negative association with increasing age, but to a lesser extent in boys than girls.

Keywords: Aerobic capacity, sex differences, maturation, body mass index, PACER

Introduction
Children's aerobic capacity, and its inverse association with obesity, remains a concern to physical and health educators. Specifically, aerobic capacity represents the highest rate of oxygen that can be consumed by working tissue during moderate to vigorous exercise [1]. Aerobic capacity is especially important as it represents the functional limits of the O_2 delivery chain and is a key indicator of cardiovascular health. On the other hand, obesity limits cardiovascular function and is a precursor of serious illness. Given the urgency of children's cardiovascular health and in light of recent secular trends [2] height (leveling off) and weight (increasing), current data is needed on children's aerobic capacity.
Aerobic capacity, or $V0_2$max, is the product of maximal cardiac output (L blood • min- 1) and arterial-venous oxygen difference (mL 0_2 per L blood) [3]. Maximum oxygen uptake is typically determined by employing maximal and submaximal treadmill tests that require large muscle groups to perform moderate-to-high intensity exercise for an extended time. Performance on these tests indicates the relative condition of the respiratory, cardiovascular and musculoskeletal systems [3, 4]. In fact, low levels of aerobic fitness are associated with cardiovascular disease (CVD), diabetes, metabolic syndrome and all-cause mortality [5-9].
Among the factors negatively associated with aerobic capacity is body mass index (BMI) [BMI = (weight in kg/(height in meters^2)]. As expected, investigators have reported that individuals with high BMI or body fat percentage demonstrated lower aerobic performance [10-14]. As is often the case, inadequate levels of physical activity are associated with obesity and therefore high BMIs [15].
Disconcertingly, the prevalence of youth identified as overweight and obese has risen in the United States during recent decades [16]. Most notably, from 1980 to 2005, the percent of youth classified as obese increased from 7 to 19 percent among US children ages 6 to 11 years, and from 5 to 17 percent in youth ages 12 to 19 years. Regrettably, aerobic performance at work, during sports and physical education, and activities of daily living may continue to decline. It is noteworthy that The Cooper Institute (2010) recently changed calculating aerobic performance for their Progressive Aerobic Cardiovascular Endurance Run (PACER), to include BMI. In field-based settings, the PACER is commonly used to estimate aerobic

capacity. Therefore, children's PACER performance was selected as the focus of the present study.

In addition to BMI, another key factor that must be accounted for when assessing youth aerobic capacity is maturation. As children enter adolescence, there are natural increases in the size of bones, muscles, heart, and lungs [17]. Thus, physical growth and maturation are naturally accompanied by an increase in aerobic capacity. This increase is due to an enhanced capacity of the heart to pump blood through the body and the lungs to exchange 0_2 and $C0_2$ [2, 18]. In fact, Matton *et al*. (2006) observed a substantial increase in peak $V0_2$ one year before, to one year after puberty. Conceptually, the point of most rapid maturation can be defined as the age at which a child experiences their peak height velocity (PHV), or the age at which they experience their most rapid growth.

Complicating matters are marked sex differences in both maturation (i.e. age at which they experience PHV) and aerobic capacity during and after maturation. Generally, girls mature two to three years earlier than do boys [18]. As girls mature, their hips widen, breasts develop and their proportional fat mass increases [2, 18]. As boys mature, they develop greater proportional muscle mass and strength, larger hearts and lungs relative to their size, longer bones, wider shoulders in relation to their hips, and greater stature overall [2, 18]. Also contributing to sex differences in aerobic capacity is boys' greater increase in red blood cells and hemoglobin levels [18]. This maturation-related hemoglobin increase generally gives boys a greater capacity for oxygen transport to the working muscles.

Additionally, changes in body shape and proportion means that boys are often mechanically advantaged in performing some physical activities. For instance, longer legs, and narrow hips relative to shoulders create mechanical efficiencies in running for speed and distance [2, 18]. Along these lines, investigators found that boys generally had a greater $V0_2$ peak, had higher aerobic capacity and performed at higher levels than did girls on aerobic fitness tests [10, 11, 14, 20, 21]. In addition to biological differences between boys and girls, investigators have also reported variance in physical activity choices. For instance, Kemper and colleagues (1989) found that boys participated in more vigorous levels of regular physical activity than did girls until adulthood, when physical activity levels were similar.

It is apparent that body mass, maturation, and sex have substantial but varying degrees of influence on aerobic capacity. Therefore, physical and health educators would benefit from current data regarding how these variables contribute to aerobic capacity. Such information is particularly relevant considering recent secular trends in youth height and weight.

The purpose of this study was to examine key biological indicators of aerobic capacity in children and youth ages 9 to 16. It was hypothesized that boys would have higher aerobic capacity (PACER) scores than girls. It was additionally hypothesized that performance differences between boys and girls would increase after PHV, with aerobic capacity continuing to increase for boys, while plateauing for girls. Finally, we hypothesized that increased body mass would have a negative association with aerobic capacity (i.e. PACER scores). The design was cross-sectional and correlational.

Materials and Methods

Initial participants were 1,903 healthy children ages 9-16 enrolled in 19 public schools. "Healthy" was defined as free from illness, injury or disability that might adversely impact aerobic performance. School officials determined which children met these criteria. Within this sample, 19 (1.0%) were eliminated from the analyses due to missing data on key variables, resulting in a final sample size of 1884 students (915 female, 969 male). Descriptive information on participants is presented in Table 1.

Table 1: Participant characteristics by sex

Variable	Female (N=915)		Male (N=969)			
	Mean	SD	Mean	SD	*t* (1882)	p
PACER	27.61	14.67	35.27	20.28	9.348	<.001
Age	12.08	1.50	12.19	1.50	1.624	0.104
BMI	21.67	5.23	21.29	5.42	1.549	0.122
Seated Height	98.25	20.89	98.74	20.85	0.509	0.611
Standing Height	152.88	10.45	154.34	12.30	2.782	0.005
Weight in Kg	51.60	16.56	51.90	18.22	0.364	0.716
Offset	0.88	1.60	0.54	2.51	3.515	<.001

Note: PACER: Pacer score; Age: Age in years; BMI: Body Mass Index; Seated Height: Measured in centimeters, Standing Height: Measures in centimeters, Weight in Kg: Weight in kilograms; Offset: Maturity offset or years past peak growth velocity.

Nineteen experienced physical education teachers, representing as many schools, agreed to assess students at their respective school. Collectively, these schools enrolled approximately 3000 children in the age range studied (9 to 16 years). In return for their contributions, teachers received individualized data on their students' aerobic performance.

The project officially began with six hours of university-based training. Faculty in exercise physiology, motor development, and measurement/statistics conducted all training. Participating physical educators received instruction related to anthropometric measurement techniques and administering the PACER. Every effort was made to standardize assessments by applying procedures consistent with the Brockport Physical Fitness Training Guide (1999).

Following training, teachers initiated data collection at their respective schools. Teachers submitted their data via the FITSTATS website-a flexible, comprehensive and customizable assessment system for schools and districts. FITSTATS tracks student progress and generates reports related to key physical education outcomes, including motor skills, health-related fitness, nutritional habits, attendance, and more. For purposes of the present study, FITSTATS was used to track participants' PACER scores and anthropometric measurements. FITSTATS is fully compatible with all district, state and national standards [23].

Anthropometric measures were taken while children wore socks and without wearing excess clothing. SECA stadiometers (model #213) were loaned by the project to schools to measure standing and sitting height. Measurement procedures previously applied by Ross and Marfell-Jones (1991) were carefully followed. The following measurements were taken:

Standing height: Standing height was the maximum distance, to the nearest centimeter, from the floor to the vertex (highest point) of the head while the student stood straight.

Sitting height: For sitting height, participants sat on a measuring box or level platform of known height with their hands resting on their thighs. Sitting height was then measured, to the nearest centimeter, as the maximum distance from the floor to the vertex of the head

Leg length: Participants' leg lengths were calculated by subtracting the sitting height from the standing height, to the nearest centimeter.

Weight: Weight was measured to the nearest kilogram.

Body Mass Index (BMI): BMI was calculated for each participant using their weight (kg) divided by height in meters squared.

Given the highly variable nature of adolescent growth and maturation, even among children of the same chronological age, it was necessary to control for the confounding effects of biological maturation. In response to this need, Mirwald, Baxter-Jones, Bailey and Beunen (2002) designed sex-specific multiple regression equations to predict years from peak height velocity (PHV). The equation for males is:

Maturity Offset = -9.236 + 0.0002708* Leg Length* Sitting Height-0.001663* Age* Leg Length + 0.007216* Age* Sitting Height + 0.02292*Weight/Height*100 [Eq.1]

For females, the equation is:

Maturity Offset = -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 [Eq. 2]

****Note:** Equations 1 and 2 are slightly different from the published formulae. Due to a typographical error in the original paper, a correction was discussed and confirmed directly with the authors. That correction is reflected in Equations 1 and 2.

Negative offset values indicate the number of years until a child reaches peak height velocity, while positive offset values indicate the number of years that have passed since the child experienced peak height velocity. Based on these equations, Mirwald *et al*. (2002) reported an R^2 = 0.891 when predicting age of peak height velocity for males, and an R^2=0.890 when predicting for females.

The Progressive Aerobic Cardiovascular Endurance Run (PACER) was used to estimate participants' aerobic capacity. Procedures specified in The Brockport Physical Fitness Training Guide (1999) were carefully applied. The PACER is often used in field-based settings to estimate children's aerobic capacity [10, 26]. Specifically, participants proceed through graded levels of exercise intensity while attempting to maintain pace to a prerecorded auditory cue. That is, participants are cued to run 20m lengths on a level surface (gym floor) at the sound of a beep.

As participants advance through each stage, they attempt to run faster to keep pace with a steadily increasing beep-frequency. For scoring purposes, failure to cover the 20m after a second attempt equals the maximum effort for that child. Therefore, a participant's score is the number of 20m lengths completed. This structured approach to assessing aerobic performance might provide a clearer picture of aerobic performance than some traditional field-based tests [10, 26]. For instance, the one-mile run time may produce too much oxygen deficit and lead to premature fatigue. The Brockport Physical Fitness Test Training Guide (1999) reports high content validity, moderate concurrent validity and high reliability, *r* =.89 for the 20m PACER. Butterfield and colleagues (2015) previously applied all aforementioned procedures. This investigation was conducted with the approval of the corresponding author's university IRB.

Results

Table 1 includes t-tests examining sex differences in PACER scores, as well as predictor variables and anthropometric measurements used to estimate maturation offset. Not surprisingly, sex differences were found in both PACER scores (t(1882)=9.348, p<.001) and standing height (t(1882)=2.782, p=.005), with male students being taller than female students and having higher PACER scores. The mean maturation offset was also significantly different based on sex (t(1882)=3.515, p<.001), with larger-more positive-offset scores for females than for males, indicating that female students reached peak height velocity at a younger age than did male students.

The correlations among PACER scores and the key continuous predictors (age, BMI and maturation offset) are reported in Table 2. Given the large sample size, all correlations were statistically significant, with the exception of PACER scores and maturation offset (r=-.008, n.s.). The remaining correlations ranged in size from .219 ($r_{BMI, Age}$) to .635 ($r_{Age, Maturation Offset}$). While not reported in Table 2, it is worth noting that the correlation between age and maturation offset was significantly larger for female (r=.777) than male (r=.584, z=7.997, p<.001) children.

Table 2: Correlation among key variables

	PACER	Age	BMI	Offset
PACER	1.000***	0.248***	-0.383***	-0.008
Age	0.248***	1.000***	0.219***	0.635***
BMI	-0.383***	0.219***	1.000***	0.389***
Offset	-0.008	0.635***	0.389***	1.000***

Note: PACER: Pacer score; Age: Age in years; BMI: Body Mass Index; Offset: Maturity offset or years past peak growth velocity. ***p<.001.

Table 3 provides descriptive information regarding mean PACER performance by age for male and female students. Means across time reflect a relative stability in performance through approximately age 12, followed by an overall increasing trend for males, and an increase and later potential plateau by females.

Table 3: Mean PACER performance by age and sex

Age in Years	Females			Males		
	Mean	SD	N	Mean	SD	N
9	27.32	12.27	28	34.88	17.68	24
10	25.62	12.85	91	29.70	16.77	105
11	25.04	13.28	234	29.70	16.19	193
12	26.40	13.30	205	31.58	16.46	231
13	28.58	15.43	228	38.35	21.01	260
14	30.78	17.70	69	39.63	24.46	97
15	37.14	16.43	35	49.87	20.57	31
16	38.04	17.14	25	65.43	24.18	28
Total	27.61	14.67	915	35.27	20.28	969

Primary analyses involved a series of multiple regressions predicting PACER performance. Predictors were child sex, age, BMI and maturation offset. Given the nonlinear nature of development during early adolescence, age was predicted to have a quadratic (i.e., curvilinear effect) on performance. A similar prediction was anticipated for BMI-with less of an impact within the normal range, but an increasing impact at higher levels of BMI. For regression analyses, age and BMI were centered on their overall means (12.14 and 21.48, respectively) in order to minimize the impact of multicollinearity with the quadratic terms and subsequent interaction effects, as well as to facilitate the interpretation of findings.

An initial model first examined the four predictors, without the quadratic terms for age and BMI. Age, BMI, and child sex were all highly statistically significant (*p*<.001), with the maturation offset also statistically significant (*b*=-.555, *t*(1879)=-2.423, *p*=.015). When added to the model, both quadratic terms were also highly statistically significant (*p*<.01), with the maturation offset no longer significant (*b*=.049, *t*(1877)=0.200, *p*=.841). Results for the initial model are presented in Table 4.

Table 4: Initial regression model

Variable	*b*	SE	ß	t(1877)	*p*
(Constant)	26.040	0.677		38.454	<.001
BMI	-1.669	0.090	-0.489	-18.543	<.001
Age	3.811	0.330	0.314	11.545	<.001
Offset	0.049	0.246	0.006	0.200	0.841
Sex	6.591	0.705	0.181	9.351	<.001
Age^2	0.707	0.122	0.123	5.813	<.001
BMI^2	0.017	0.006	0.067	2.745	0.006

Note: PACER: Pacer score; BMI: Body Mass Index; Age: Age in years; Offset: Maturity offset or years past peak growth velocity; Sex: Child Sex (female=0, male=1).

Based on the initial model, a final model was developed that included possible interactions among predictor variables. Development of this final model proceeded in two steps. First, six analyses tested each of the interactions between the four predictors (child sex, age, BMI, and maturation offset) individually. Three of these were statistically significant: BMI x Sex (*b*=-.287, *t*(1876)=-2.180, *p*=.029), Age x Offset (*b*=-.702, *t*(1876)=-4.131, *p*=<.001), and Age x Sex (*b*=1.843, *t*(1876)=-3.964, *p*=<.001). It should be noted that all three continued to be statistically significant even if the model included all six, interaction terms, suggesting they were individually robust and provided a unique contribution to the model.

The second step in developing the final model involved testing possible quadratic interactions of (a) Sex and (b) Maturation Offset with the quadratic Age^2 and BMI^2 terms, as well as a BMI x Age^2 interaction and an Age x BMI^2 interaction. Two of these six quadratic interactions were statistically significant: Maturation Offset x Age^2 (*b*=-.222, *t*(1874)=-3.366, *p*=.001) and Sex x Age^2 (*b*=.610, *t*(1874)=2.699, *p*=.007). The final model incorporated the three linear interactions and two quadratic interactions. As reported in Table 5, all predictors and interaction terms were statistically significant.

Table 5: Final regression model

Variable	*b*	SE	ß	t(1877)	*p*
(Constant)	**26.190**	**0.713**		**36.757**	**<.001**
BMI	-1.487	0.112	-0.436	-13.300	<.001
Age	3.490	0.486	0.288	7.180	<.001
Offset	0.455	0.267	0.053	1.700	0.089
Sex	5.612	0.859	0.154	6.532	<.001
Age^2	0.995	0.227	0.173	4.376	<.001
BMI^2	0.021	0.006	0.083	3.405	0.001
BMI x Sex	-0.382	0.134	-0.082	-2.853	0.004
Age x Offset	-0.597	0.183	-0.100	-3261	0.001
Age x Sex	1.302	0.519	0.077	2.509	0.012
Offset x Age^2	-0.157	0.068	-0.083	-2.306	0.021
Sex x Age^2	0.466	0.234	0.065	1.988	0.047

Given the complexity of the interactions, two figures can help clarify these effects. Figure 1 shows predicted PACER scores based on a child's age, sex, and whether he or she matured early (peak height velocity at 10 years of age) or late (peak height velocity at 14 years of age). While males had overall higher PACER scores, relatively little difference was observed among males or among females based on early/late maturation prior to approximately 12 or 13 years of age. After 13 years of age, both males and females who experienced later maturation showed steadily higher PACER scores. However, early maturing females showed less increase with age, and their scores appeared to plateau at a lower level. Early-maturing males showed larger gains, although less than late-maturating males with a possible start of a plateauing effect at the upper age-range.

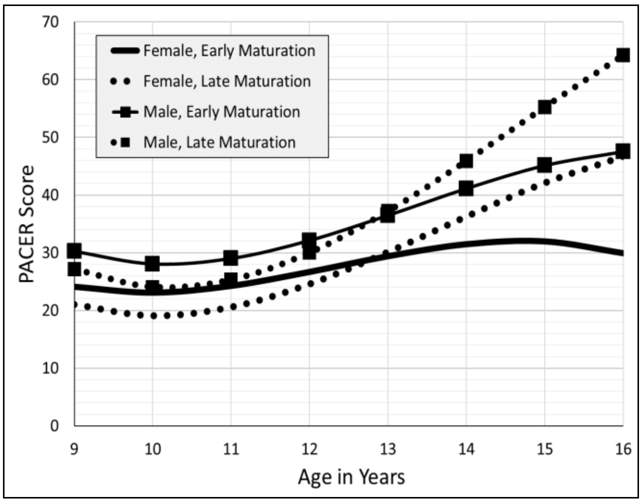

Fig 1: PACER scores based on age, sex and early/late maturation

Figure 2 depicts the predicted PACER performance based on BMI for a child at the mean age (12.14 years) and maturity offset for their sex at that age (females=.94, males=.49). BMI values used in the figure range from 15, or the 3.1 percentile, to 32.5, or the 96.2 percentile. As anticipated, PACER performance for males was higher than females; however, both declined with increased BMI. The decline in performance based on BMI was greater for males, resulting in nearly identical predicted scores at the upper BMI range. For context, 3.1% of children had BMI scores below 15, while 46.6% had BMI scores from 15 up to 20, 29.2% had BMI scores from 20 up to 25, 13.6% had BMI scores from 25 up to 30 and 7.5% had BMI scores of 30 or more.

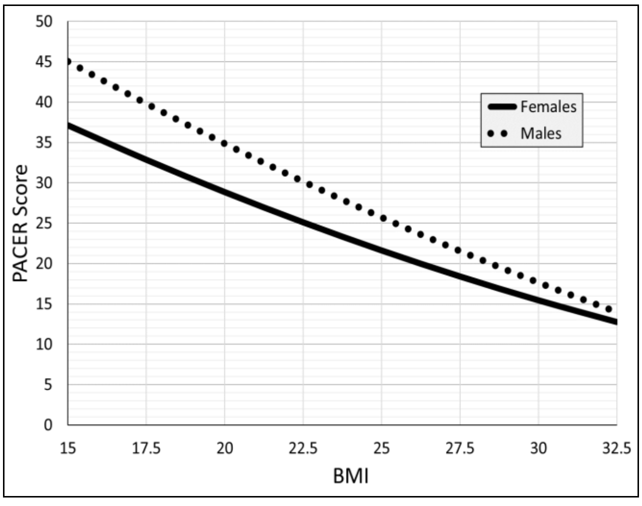

Fig 2: PACER scores based on child sex and BMI

Discussion

Results indicate that body mass, age, sex and maturation all contributed to PACER performance and, thus, aerobic capacity. As hypothesized, chronological age was positively correlated with PACER scores. This result is consistent with previous investigations as increases in the length and size of bones, muscles, heart and lungs, lead to increased aerobic performance [2, 17, 18].

In terms of sex differences, at age sixteen, both boys and girls, in the present study, recorded their highest mean PACER scores, with girls at 38.04 laps and boys achieving 65.43 laps. These findings are meaningful, as boys' scores were nearly twice that of girls. An explanation for this result points to biological maturation and associated sex differences. For instance, Abbassi (1998) estimated that PHV occurs in boys at 13.5 years and in girls, at 11.5 years. Abbassi's finding is consistent with Tanner's (1971) assertion that females mature physically two to three years earlier than do males. In the present study, maturation offset had a negative association with increasing age, but to a lesser extent in boys than girls. Kemper, Verschuur and DeMey (1989) found that girls, on average, plateau or decrease in PACER scores after reaching PHV while boys continue to improve. However, in the present study, this result occurred for early maturing girls, but not for late maturing girls.

In addition to adolescent physiological maturation, another possibility is a change in interests, especially among girls, to less aerobic activities [21]. In consequence, when the physiological systems in the body are not stressed on a regular basis, aerobic capacity decreases [14]. Another possible explanation for the large difference between the sexes are cohort effects [28]. Such effects might be associated with bias regarding girls' participation in sports and physical education. While Title IX, ensuring equal opportunities for women and girls in sports, was enacted in 1972, bias may still exist in methods used to encourage boys and girls to participate in sports. Such bias and discrimination would likely result in fewer opportunities for girls and therefore lower aerobic performance.

The overall performance differences between boys and girls can be somewhat explained by maturation, including gains in strength and coordination that may have contributed to improved running form. The increased percentage of adiposity and widening hips among pubertal and post-pubertal girls coupled with boys' gains in muscle mass, are additional sources of performance variability. Along with these obvious changes, boys have an increase in red blood cells and hemoglobin associated with the presence of testosterone thereby increasing oxygen transport capacity and carbon dioxide removal [18]. Another explanation is that, in general, boys remain more aerobically active than do girls during and after puberty, thus contributing to boys more rapidly increasing aerobic capacity through adolescence [21].

The present findings were consistent with previous reports related to sex differences in aerobic capacity [10, 11, 14, 20, 21]. On the other hand, Laaneots, *et al*. (1996) found that girls' $V0_{2max}$ increased substantially throughout puberty, whereas the present study indicated a plateau. Specifically, in the present study, a plateau existed for early maturing girls but not for late maturing girls.

Regardless of sex differences, as BMI increased, PACER scores declined. This negative association stands to reason as the body has to work harder to maintain pace. Present findings are therefore in line with prior investigations regarding the influence of body mass and aerobic performance [10-14].

Overall, the findings of this study are likely relevant to physical educators. Knowing the interactions between BMI, age, sex and maturation on PACER score and aerobic capacity, physical educators would be better able to plan appropriate activities for their students. Also noteworthy are percentages of BMI classifications for their students. This aspect of the study indicates current anthropometric data on youth, which should be of value to health professionals.

Some important factors that may also affect PACER scores and aerobic capacity are physical activity levels including organized sport participation and the instructional nature of repeated measurements. For instance, Butterfield and colleagues (2008) observed that participants significantly improved after the first two trials of the PACER. These investigators reasoned that participants became familiar with the test and learned to better pace themselves and thus sustain performance. Physical activity is a known influence on aerobic capacity and some studies have shown sports participation to be associated with aerobic capacity [10]. As physical education class times are reduced and many youths now lead a generally sedentary lifestyle, there is a need for current information on how reduced physical education time impacts children and adolescents. A longitudinal study would likely extend the present study by more closely examining how age, BMI, maturation and sex, along with related variables such as physical activity, affect PACER score and therefore aerobic capacity.

Directions for further study meaningful to physical education and health, are apparent. One possible avenue is to examine Mirwald *et al*.'s (2002) maturation-offset equations to determine the extent to which they are generalizable and if so, what limits or modifications to the equation may exist. Possible refinement of the Mirwald, *et al*. (2002) equations could lead to the development of an 'app' for use by pediatricians and sports physicians during sports physical examinations. Resulting information could be used to counsel parents and guardians on developmentally appropriate levels of competition for their children. This application would no doubt be an improvement on the arbitrary age-based classifications currently in use by many youth sports leagues. Another direction would be to examine the differences in estimated aerobic capacity based on The Cooper Institute's (2010) current and former equations and examine research related to changing the equation to include BMI.

Conclusion

As anticipated, all children demonstrated improved PACER scores with age; but boys generally completed more laps than girls. BMI also had a substantial effect on PACER scores. In terms of maturation, distance from PHV also had an impact on PACER performance as children who matured late performed better than those who matured early. We further concluded that university-public school partnerships are viable and if conducted systematically, can benefit all parties.

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