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Original Article

Differences in muscle power and aerobic endurance in pre- and post-menarche girls during mid-adolescence: A two-year follow-up study

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Abstract
Problem Statement: Research indicates that early- and late-maturing girls' physical fitness skills are influenced differently by anthropometric changes, initially favouringearly maturing girls. **Purpose**: The aim of the study, therefore, is to investigate differences in pre- and post-menarche girls' physical fitness capabilities. **Approach:**: Over three school years, fifty-eight (N=58) girls with a mean age of 13.51±3.51, were divided at baseline into a pre- (n=13) and post-menarche group (n=45) for comparison of muscular power and aerobic endurance. Measurements were taken annually (2010-2012) providing data over three time points. The Australian Sports Commission (1996) protocol was used. Basic statistics, a Spearman correlation analysis, and a repeated-measures ANOVA, adjusted for with a Bonferroni post hoc correction were applied. **Results:** Developmental differences between the pre- and post-menarche groups were relatively small and insignificant. Early menarche status was to the advantage of power while reaching menarche later positively affected aerobic endurance at younger ages. Changes in these abilities over the follow-up period were different in the groups and levelled out most differences during final measurements. **Conclusion**: Timing of menarche contributed to differences in muscle power and aerobic endurance of girls, particularly during mid-adolescence, although only on a practical level. The period at and immediately after reaching menarche is characterized by instability, with changes in power and endurance that are associated with menarche status. Influences of somatic and biological growth in same-aged girls of the same age and the influence thereof on power and endurance will only be levelled out 1-2 years after reaching menarche.
Keywords: Endurance, Growth, Longitudinal, Menarche, Power

Introduction

The adolescent period, including puberty, refers to the transition from childhood to adulthood. It is a unique period of growth and development characterized by multiple physical and physiological changes (Gaudineau*et al*., 2010; Sawyer*et al*., 2018). The most noticeable anthropometric, physical and motor changes are found during the adolescent period when a so-called overflow effect occurs in various biological and physiological systems. This overflow effect results in changes that occur in one aspect, affecting changes in surrounding or related aspects. The first onset of menstruation, referred to as menarche (Rubin *et al*., 2009; Hozoori*et al*., 2017) is one of several factors that are associated with other physical changes occurring during puberty (Marshall & Tanner, 1969). In the late forties, the research of Espenschande (1947) already showed that the ability of an individual to manage its body through childhood, adolescence and maturity varies markedly as a result of various individual differences in the precision andability with which movements are made. Researchers report that pubertal changes influence the development of motor and physical fitness of girls during adolescence (Vijayakumar *et al*., 2018) which again influences the physiological and muscular-skeletal system of growing children.

This physical ageing from pre-pubertal age to adulthood represents a continuum that includes both early and late developers (Hoyt *et al*., 2020) which will consequently have influence the physical fitness development of girls in different stages of development differently. During puberty, an acceleration occurs in the growth of organs such as the heart and lungs (Bitar*et al*., 2000; Biro & Chan, 2017). This growth plays an important role in an improved aerobic capacity as more oxygen can be absorbed and distributed through the body. It is reported in this regard that heart and lung function increase linearly with age and height until the adolescent period. Mahmoud*et al.* (2018) also reported that lung function does not increase proportionally to height during adolescence but rather follows a more complex pattern. Initially, trunk length lags behind leg length temporally;

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then the lung grows in diameter followed by length and finally, lung volumes continue to increase after adult height has been reached due to prolonged increase in muscle strength. Females develop more distensible large arteries post-puberty according to researchers(Ahimastos*et al.* 2003; Mahmoud *et al*., 2018*).* Growth of the human heart is again closely associated with somatic growth duringchildhood which includes increases in body weight, fat-free body mass (FFM), and height. However, greater variability in heart size in relation to body size is observed with increasing age, which is presumably attributable to the increased effect of cardiac workload. Aberberga-Augskalne and Kemper (2007) found that the greatest increase in the pace volume of the heart takes place approximately one year before peak hight velocity (PHV) among girls with an average increase of 19 ml/min annually. The age at which menarche occurs is not rigid and is influenced by a variety of factors, such as genetic factors, nutrition and health status (Sawyer et al., 2018) as well as physical activity (Castilho *et al*., 2015; Lee *et al*., 2016)

Physical ageing from pre-pubertal age to adulthood represents a continuum that includes both early and late developers (Hoyt et al., 2020). Early, average and late development in females is classified according to the timing and deviation of reaching menarche, compared to average values, which is considered to be reached at approximately 12.4 years within a certain population (Malina *et al*., 2004). Biological variation is reported to influence the development of motor and physical fitness of adolescentgirls (Bronikowski&Bronikowska, 2008; Balyi& Way, 2010). Therefore, it can be argued that the timing of these physiological changes will influence the physical fitness capabilities of girls of differing pubertal status at a specific chronological age.

Physical fitness refers to the capacity to perform daily activities and tasks without any unnecessary exhaustion (Gallahue, Ozman& Goodway, 2012;Gu *et al*., 2016). Performance- and health-related physical fitness requires body control, especially muscle control and coordination (Sener*et al*., 2016) and includes muscle power, muscle endurance, aerobic endurance, flexibility, and body composition. Performance-related physical fitness is considered to be important elements of sports success and includes abilities such as running speed, power and agility (Gu *et al*., 2016; Gallahue*et al*., 2012). In this regard, player selection of sports teams before puberty are mostly based on favourable physical characteristics, which can be the result of early maturation. This elimination of late-developing girls is not necessarily optimal, as it may limit them in receiving the necessary opportunities to excel in sport due to their unfavourable physical characteristics (Williams & Reilly, 2000). However, research shows that early developers cannot necessarily maintain the benefits of early maturation due to them being affected negatively at earlier ages, by pubertal changes, such as hormonal changes (Vaeyens*et al*., 2008). Therefore, research pertaining to differences in the development of physical fitness of early and late-developing girls, where biological age instead of the chronological age are used, will aid in the better understanding of the nature and extent of developmental differences between girls of differential maturity levels. Such knowledge will especially aid in optimizing training benefits forall girls who want to participate in sport.

The long-term effects of reaching puberty and subsequently menarche at an earlier or later age and its relation to physical fitness capabilities have for some time been a subject of research (Apter*et al*., 1989; Forman *et al*., 1994; Van Lenthe*et al*., 1996; Okasha*et al*., 2001). In this regard research aimed to provide knowledge on the immediate and long-term effects of differential timing of menarche *(*Vaeyens*et al*., 2008). Also, to determine the importance of taking biological maturation rather than chronological age into account, during research and sports classification of youths, to correct for developmental differences.

Various growth studies have been conducted worldwide (Rodriguez *et al*., 2004; Deborah & Russel, 2005; Frederics*et al.*, 2005; Garnier *et al*., 2005; Anderson, 2009) including in South-Africa (Henneberg&Louw, 1995; Van Gent, 2001; Van den Berg *et al*., 2006; Travill, 2007), focusing on the anthropometric, motor- and physical changes that take place in girls during adolescence. Such influences were also explored in international studies (Prahl-Anderson *et al.,* 1994; Beunen*et al.,* 1997; Kemper *et al*., 2004; Lee *et al*., 2005; Volver *et al*., 2007) and to a lesser extent in South-Africa (Monyeki*et al*., 2006; Richter *et al*., 2007). However, the age of onset of menarche (biological maturity), and the differences that may arise in the physical make-up of females of differing maturity status, were not the main differential factor in these analyses. In addition, few longitudinal studies could be found that consider different influencing factors in their analyses of differences between females of differing maturational status. Therefore, this study aims to address this void regarding the nature and extent of developmental differences in physical fitness of early and late maturing girls during the mid to late adolescence period. Findings from this longitudinal study will aid in providing knowledge on the extent to which reaching of menarche at different ages will influence the power and aerobic endurance development of girls.

Materials and methods

Research design

This study made use of a longitudinal research design. The main project, titled "Growth and sport psychological characteristics of talented adolescents", were performed over a 3-year school period (2010-2012). The data was collected using anthropometric, physical and motor tests as well as questionnaires. The anthropometric measurements took place three times a year (4 months apart) with the physical and motor tests only measured once a year during the first measurements of each school (T1) year. Baseline measurements were taken in February 2010 (T1), and the last measurements took place in November 2012, resulting in nine time-point measures for growth and three time-point follow-up measures for physical fitness. Overall, follow-up measures were obtained over a two-year period. The results of only the time-point measures for fitness will be used in this study which was obtained in Feb 2010 (T1), Feb 2011 (T2) and Feb 2012 (T3).

Research group

All grade 8-learners of one quintile 5 school (quintile 1=low socio-economic quintile, to quintile 5=high socio- economic) in Potchefstroom in the Northwest Province of South-Africa, were invited to take part in the study. Learners who had parental permission and who gave consent themselves were subjected to the testing protocol. Approval for the project was also obtained from the principal of the school. Since the school had boarding facilities, all grade 8 learners enrolled in 2010 represented 46 different primary schools. In 2010, 200 subjects (girls n=95; boys n=105) with a mean age of 13.73±0.48 years participated in the study. Only the girls formed part of this study. The final group, who completed all follow-up measurements in November 2012, consisted of 58 girls with a mean age of 16.27±0.36 years. The group largely comprised Caucasian South-African girls (96.5%) while the remaining 3.5% included black African and mixed-race girls. The loss of subjects to follow-up were 37 girls (38%) due to various reasons including parents of children moving out of town, children moving between schools and injury.

Ethical approval

Ethical approval was obtained from the Health Research Ethics Committee of the North-West University's Potchefstroom campus (NWU 00142-11-A1 and NWU 00199-15-A1) for the execution of the study.

Measuring instruments

Age of menarche

The age of menarche was determined by the Status Quo method (Hennenberg&Louw, 1995; Wang *et al*., 2016)during the first measurements of each year in February 2010, 2011 and 2012 (T1, T2 and T3). Only questionnaireswere used to determine the Status Quo of menarche and the chronological age of reaching menarche. Theparticipants had to report their menarche status by means of completing a questionnaire at baseline and at thebeginning of each of the follow-up years where they had to select a YES or a NO to the question whether they havehad their first menstrual cycle on or before the date of testing. If the participant answered YES, a follow-up questionhad to be completed by indicating the month and year when her first menstrual cycle took place. There were nointerviews to verify the data.

All comparisons in this study were based on the baseline classification at T1 of the participants into a pre and postmenarche group. Table 1 shows that the majority of the group (77%, n=45) had already reached menarche during thebaseline measurement (grade 8 - 2010) at a mean age of 13.51 years, who represented the post-menarche group inthis study. The remaining thirteen participants (n=13) represented the pre-menarche group. The group's overallmenarche status did change over the two follow-up years of the study. Eight participants, representing 91% (n=53) ofthe total group, reached menarche during the first follow-up measurements (grade 9 - 2011) at a mean age of 14.52years with all but one participant (98%) reaching menarche at a mean age of 15.52 years during the last year ofmeasurements (grade 10 – 2012).

Anthropometric measurements and body composition

Stature was measured to the nearest 0.1cm by means of a portable Harpenden stadiometer (Harpenden HoltainLtd,Crymych, UK). The measurement was taken with the subject standing, facing forward, with the heels, back and headagainst the stadiometer and with feet standing together. The head was held in the Frankfort position by the examiner,and the measurement was taken after the subject had inhaled deeply, to the nearest 0.1cm. Two measurements weretaken, of which an average value was used (Stewart et al., 2011). Mass was measured by means of an electronicallycalibrated scale (Omro BF 511). The subject stood upright with weight evenly distributed over the scale with thearms at the sides of the body. The subject had to look straight forward while standing without shoes and as littleclothing as possible and the measurement was then taken to the nearest 0.1 kg (Stewart et al., 2011). From thesemeasurements, body mass index (BMI) was calculated by using the following formula: Bodyweight in kilogramsdivided by height in meters squared or, BMI = x Kg / (y M * y M) (x=bodyweight in Kg, y=height in M). Bodycomposition variables were also analysed. Percentages of body and muscle mass were determined by using anelectronically calibrated bio-impedance, body composition apparatus (Omro BF 511). The validity of the OmronBF511 is as follows: ±0.4 kg variation in mass in participants 0-40 kg, ±1% variation in percentage body fat and3.5% in percentage muscle mass within-participant ranging between 40-150 kg: (www.omron-healthcare.com).Compared with %FMDXA, and SMMRI measurements, the Omron show correlations of r^2=0.84 - r^2=0.92.

Physical Fitness measurements

Power

The **cricket ball throw** was used to test upper-body shoulder and chest power. During the cricket ball throw test, thesubject had a 10m run-up to throw a cricket ball (224mm, 156 grams) as far as possible. During the run-up before thethrowing action, the participant was not allowed to touch or cross the line from where the measurement was taken.Two attempts were awarded, of which the best attempt was recorded in meters (Topendsport, 2012).

Aerobic endurance

The indirect multistage **Beep-test** (Leger & Lambert, 1982) was used to determine aerobic endurance. It is a 20-meter running test with a progressive increase in intensity/speed each time a new level is reached. Each level in thetest consists of a number of beeps, which must be completed before a new beep or level begins. The results of thebeep-test are noted as the total "shuttles" and levels completed (Leger & Lambert, 1982, Australian SportsCommission, 1996). Absolute and relative $\dot{V}O^2$max were both calculated from these results. Absolute $\dot{V}$ O2max(maximal oxygen uptake per minute measured in ml/kg/min taking a person's body weight into consideration) wascalculated by using the equation $\dot{V}O^2$max=41.76799 + (0.49261xPACER) – (0.00290xPACER^2) – (0.61613xBMI) +(0.34787xGenderxAge) (Matsuzaka, 2004). Relative $\dot{V}O^2$max (maximal oxygen uptake per minute) portray $\dot{V}O^2$maxwithout taking body weight into consideration and was reported in ml/min.

Statistical analysis

The data were analyzed with "Statistica for Windows 2018 (StatSoft, 2018). Descriptive statistics, including means,standard deviations (SD) and minimum and maximum values were determined. As a first step, Spearman correlationanalysis was performed to determine possible correlations between physical fitness skills and possible confoundersthat were identified as possible influences (stature, mass, chronological and biological age). A repeated-measuresANOVA was used to analyse changes in physical fitness over time with a PosthocBonferonni adjustment todetermine the statistical significance of differences between measurements amongst the two groups ($p<0.05$). Ifcorrelation analyses revealed significant influences of confounders, an ANCOVA was performed to control for theidentified confounders.Independent t-testing was used to analyse time point differences between the groups, where a p-level of <0.05 wasconsidered as a significant difference. Effect sizes were calculated to determine practical significance of groupdifferences using Cohen's d-value with d>0.2=small effect size, d>0.5 (medium effect size) and d>0.8 (large effectsize) (Cohen, 1992).

Results

Table 1 reports the descriptive characteristics of the pre- and post-menarche groups at baseline (Feb 2010) and at thetwo follow-up measurements (Feb 2011 and Feb 2012).This study provided two-year follow-up data of differences in fitness of girls classified as pre- and post-menarche inthe age period ranging between 13.51 and 15.51 years. All follow-up comparisons between these groups were madebased on the baseline grouping. Sixty-eight percent of the post-menarche group reached menarche within 12 monthsof the baseline measurements while 2% reach this milestone within 2 months of the baseline measurements. In thepre-menarche group, all but one participant reached menarche during the last follow-up measurement (T3) in Grade10 at an age between 16 and 17 years. No significant chronological age differences (0.01 years) were found betweenthe pre- (n=13, 23%) and post-menarche (n=45, 77%) groups.The first step of this study was to determine if height, body mass, chronological and biological age should be considered as confounders in the analysis of the differences between the groups. Table 2 reports the results of this analysis. Chronological and biological age did not correlate significantly with any of the fitness measures and were therefore excluded as confounders and not controlled for in any of the further analyses. Body mass correlated significantly with 4 of the 5 physical fitness measures showing the most significant correlation between stature and absolute $\dot{V}O^2$max. Stature and mass were controlled for in the absolute $\dot{V}O^2$max analysis, while only body mass was controlled for in the further analysis for aerobic endurance and relative $\dot{V}O^2$max.

Table 3 displays the body composition of the pre- and post-menarche group during T2 (Grade 9) and T3 (Grade 10). Unfortunately, no data of this nature is available for T1 due to the body composition apparatus that were only available from T2.The pre-menarche girls had an advantage in percentage muscle mass during T2 and T3 while differences between the groups stayed unchanged from T2 (1.26%) to T3 (1.25%). Differences were not of statistical significance ($p>0.05$) at T2 although it showed medium practical significance (d=0.61). The post-menarche group displayed a higher percentage body fat (T2, T3) during the course of the study although differences between the groups decreased from T2 (4.82%; $p<0.05$, d=0.68) to 2.71%, $p>0.05$) at T3. This difference at T3 was still of small

Table 1: descriptive characteristics and timing of onset of menarche of the pre- and post-menarche groups

	Year 1 (T1)		Year 2 (T2)		Year 3 (T3)	
	N	**Mean age±SD**	**N**	**Mean age±SD**	**N**	**Mean age±SD**
Group	58	(Feb)13.51±3.50	58	(Feb) 14.51±3.51	58	(Feb) 15.51±3.51
		(Dec) 14.26±3.50		(Dec) 15.26±3.51		(Dec) 16.26±3.51
Pre-menarche	**13**	**(T1) 13.52±3.58**	**13**	**(T2) 14.52±3.58**	**13**	**(T3) 15.52±3.58**
Post-menarche	**45**	**(T1) 13.51±3.53**	**45**	**(T2) 14.51±3.53**	**45**	**(T3) 15.51±3.53**
Time of onset of menarche in pre- and post-menarche group						
Post-menarche				**Pre-menarche**		
Grade 5	**4**	**8.8%**		**0**		**0%**
Grade 6	**10**	**22.2%**		**0**		**0%**

Grade 7	**30**	**66.7%**	**0**	**0%**
Grade 8	**1**	**2.3%**	**2**	**15.4%**
Grade 9	**-**	**-**	**4**	**30.8%**
Grade 10	**-**	**-**	**6**	**46.2%**
Grade11+	**-**	**-**	**1**	**7.6%**

T1=Year one (Gr8); T2 Year 2 (Grade 9); T3=Year 3 (Grade 10); N=number of participants; M=Mean age

Table 2: correlations and significance of correlation between physical fitness measures, anthropometric measures, biological- and chronological age

Variables	Stature	Mass	Biological age	Chronological age
Muscle power	0.23	-0.07	-0.19	0.22
Aerobic endurance	0.05	-0.41*	-0.25	0.26*
Relative **$\dot{V}O^2$max**	0.03	-0.54*	-0.40*	0.24
Absolute **$\dot{V}O^2$max**	0.76*	0.57*	-0.28*	0.13

*=Significant correlation

practical significance. The BMI of the pre- and post-menarche groups did not differ significantly (p>0.05) during T2or T3 although the differences between the groups (post-menarche group higher) were of small practicalsignificance. Table 4 and Figure 1(a-d) report the descriptive statistics of the muscle power and aerobic endurance (level) of thegroups, also reported as absolute and relative V̇ O2max, as well as the significance of differences between the groups.

Table 3: body composition of the pre- and post-menarche group during t2 and t3.

	Pre	Post	Difference	p-value	d-value
	T2 (Grade 9)				
Stature (cm)	162.30±8.61	164.41±6.68	2.11	0.035	0.27#
Mass (kg)	55.63±12.73	60.46±9.62	4.83	0.14	0.42#
Fat %	21.02±7.62	25.84±6.45	4.82	0.02*	0.68##
Muscle %	34.90±2.63	33.38±2.33	1.25	-2.02	0.61##
BMI	21.02±4.07	22.36±3.36	1.34	0.23	0.35#
	T3 (Grade 10)				
Stature (cm)	164.65±8.90	165.16±6.61	0.51	0.82	0.06
Mass (kg)	58.79+12.22	61.11+8.82	2.32	0.45	0.21#
Fat %	26.26±10.01	28.97±7.54	2.71	0.29	0.31#
Muscle %	40.24±5.68	38.98±4.25	1.26	0.39	0.25#
BMI	21.65±3.78	22.49±2.91	0.84	0.39	0.25#

T2=First follow up measurement (Grade 9); T3=Second follow up measurement (Grade 10); Pre=Pre-menarche; Post=Post menarche; *=Statistical significance (p<0.05); #=small effect size (d<0.2); ##=medium effect size (d<0.5); ###=large effect size (d<0.8)

Significance of changes in these muscle power and endurance variables (T1-T2, T2-T3, T1-T3) for each group, are also displayed in Table 5. The post-menarche group showed higher mean values compared to the pre-menarche group in muscle power at each time point, and from T1 to T3, with the most significant throwing difference found during the first year (3.53m, 13.51-14.51 years; Table 4). Group differences over time were not significant (F=1.53; p=0.22; Table 4).The pre-menarche group showed a gradual increase in muscle power throughout the study, compared to a small decline (-0.71m) that was found in the post menarche group 22.95m (T1) to 22.13m (T2) (Table 4, 5; Figure 1a). This resulted in a smaller difference in the muscle power of the pre- and post-menarche groups at 14.51 years (T2) and 15.51 years (T3), although the post-menarche group still displayed higher, although non-significant mean values (p>0.05) than the pre-menarche group at each of these time points. These differences of 3.53m (T1, d=0.50), 1.66m (T2, d=0.26) and 2.56m (T3, d=0.38) between the groups, were, however, of practical significance (Table 4).

Table 4: physical fitness characteristics and differences between the pre- and post-menarche groups at t1, t2 and t3

Pre-menarche (n=13)				**Post-menarche (n=45)**					
TP	**M ± SD**	**Min**	**Max**	**M± SD**	**Min**	**Max**	**Diff**	**p-value**	**d-value**
Power (meters) (Maturity group*Time F=1.53, p=0.22)									
T1	19.42±6.60	10.34	34.90	22.95±7.60	9.29	44.00	3.53	0.13	0.50##
T2	20.47±5.80	11.80	32.00	22.13±6.91	12.10	40.30	1.66	0.43	0.26##
T3	21.23±5.81	14.33	30.37	23.79±7.39	11.88	39.59	2.56	0.25	0.38#
Aerobic endurance (Level) (Maturity group*Time F=1.17, p=0.28)									
T1	5.53±1.68	4.55	6.51	5.49±1.76	4.87	6.10	0.04	0.74	0.03
T2	5.69±1.69	4.70	6.67	5.92±1.78	5.30	6.53	0.23	0.39	0.13
T3	5.99±1.85	4.91	7.07	6.46±1.94	5.78	7.13	0.47	0.12	0.24#
Absolute $\dot{V}O^2$max (Maturity group*Time F=0.04, p=0.84)									
T1	2.16±0.30	1.99	2.34	2.18±0.29	2.07	2.28	0.02	0.92	0.04
T2	2.45±0.34	2.25	2.65	2.35±0.32	2.23	2.46	0.10	0.41	0.29#

T3	2.57±0.39	2.34	2.80	2.37±0.37	2.24	2.50	0.20	0.16	0.51##
Relative $\dot{V}O^2max$ (Maturity group*Time F=3.25, p=0.07)									
T1	42.70±4.12	40.31	45.09	41.30±3.96	39.94	42.66	1.40	0.08	0.34#
T2	42.70±4.68	39.65	45.08	41.97±4.50	40.42	43.52	0.73	0.12	0.08
T3	42.16±6.48	38.41	45.91	41.80±6.22	39.66	43.94	0.36	0.16	0.06

T1=Baseline measurements (Grade 8), T2=First follow-up measurement (Grade 9); T3=Second follow-up measurement (Grade 10); Pre=Pre-menarche; Post=Post menarche; TP=Time points; $\dot{V}$ O2max =maximum oxygen uptake; *=Statistical significance (p<0.05); #=small effect size (d<0.2); ##=medium effect size (d<0.5); ###=large effect size (d<0.8)

Pre-menarche girls initially had a small insignificant aerobic endurance advantage although post-menarche girls surpass them from T2 onwards. Differences between groups were however statistically insignificant (p>0.05) during all time point measurements although group differences increased during each measurement. Only differences at T3 (d=0.24) were of small practical significance. The post-menarche group showed a higher mean improvement from T1 to T2 (0.38 levels vs 0.10 levels) and from T2 to T3 (0.50 levels versus 0.22 levels) (Table 5, Figure 1b). Only the post-menarche group showed small practical significant changes (increases) of 0.50 levels (T2-T3) and 0.88 levels from T1 to T3 (Table 5). Interactions in changes over time were not significant (p=0.346, Figure 1) while group differences over time were also insignificant (p=0.28) (Table 4).Regarding aerobic endurance expressed as $\dot{V}O^2max$, pre-and post-menarche girls' absolute $\dot{V}O^2max$ increased during all measurements with the pre-menarche group having the biggest increases of 0.23 L/min (d<0.5) vs 0.14 L/min (d>0.2) from T1 to T2 and 0.04 L/min (d>0.2) vs 0.02 L/min from T2 to T3 (Table 5).

Table 5: significance of changes in anthropometric and physical fitness characteristics of pre- and post-menarche groups

	T1-T2		T2-T3		T1-T3		Interaction in changes over time, Pre vs Post
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**p-value**
Muscle power (m)	1.47	-0.71	0.58	1.53	2.05	0.83	0.389
Aerobic endurance (levels)	0.10	0.38	0.22	0.50#	0.32	0.88#	0.346
Absolute $\dot{V}O^2max$	0.23##	0.14#	0.04#	0.02	0.28###	0.14#	0.182
Relative $\dot{V}O^2max$	-0.33	0.37	-0.57	-0.69	-0.90	-0.33	0.931

T1=Baseline measurements (Grade 8), T2=First follow-up measurement (Grade9); T3=Second follow-up measurement(Grade 10);Pre=Pre-menarche;Post=Post-menarche;*=Statisticalsignificance(p<0.05);#=small e ffectsize(d<0.2); ##=medium effect size (d<0.5); ###=large effect size(d<0.8)

Differences in absolute$\dot{V}O^2max$ at each time point were not significant (p>0.05) (Table 4). In turn, group difference over time (p=0.84, Table4) as well as interactions in changes over time (p=0.182, Table 5) were insignificant.The relative $\dot{V}O^2max$ of both groups were very similar at T3 compared to T1 with no significant changes (p>0.05)between time points or interactions in changes over time between T1 and T3 (p=0,182, Table 5).

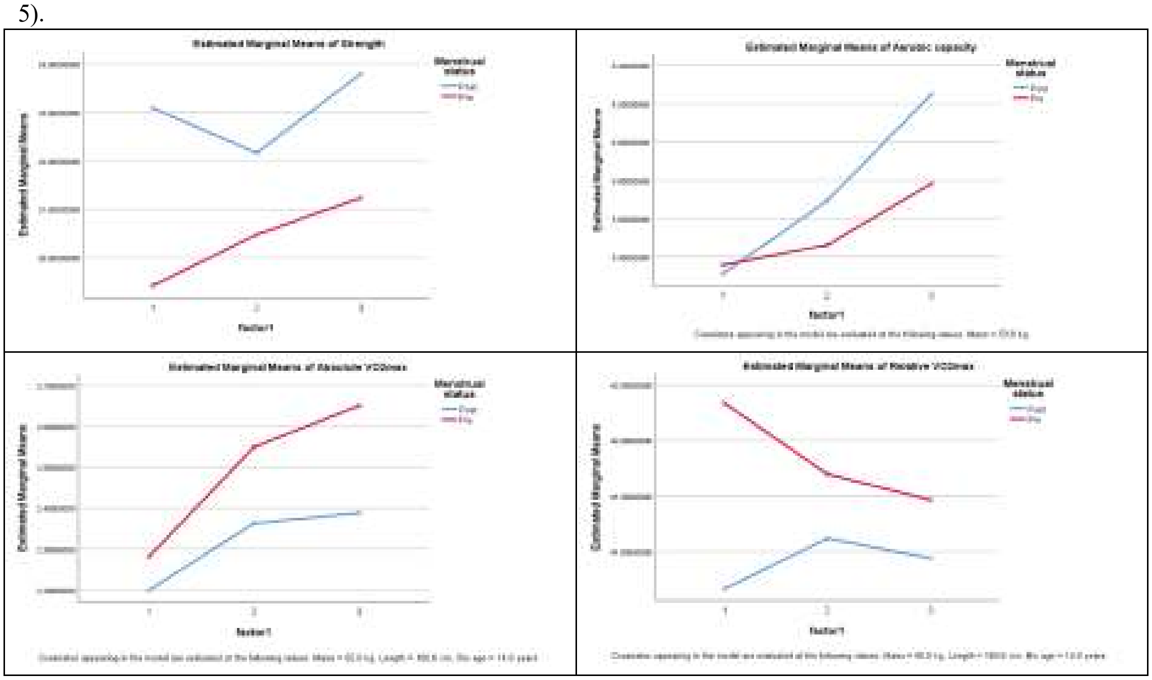

Figure 1 (a-f): Anthropometric growth curve characteristics of the pre- and post-menarche groups. Vertical bars denote 0.95 confidence intervals; T1=Grade 8; T2=Grade 9; T3=Grade 10

Discussion

The objective of the study was to address the void regarding the nature and extent of developmental differences inphysical fitness of early and late maturing girls during the mid to late adolescence period. This aim was investigatedby comparing pre- and post-menarche girls based on their menarche status when they entered their first high schoolyear at a mean age of 13.51 years. Adjustments were made in the analysis where we determined that mass and staturecould have confounding influences.Our first finding was that developmental differences between the pre- and post-menarche groups were relativelysmall and insignificant regarding muscle power and aerobic endurance. These results are consistent with otherresearch findings (Henneberg&Louw, 1995, Van Gent, 2001, Fredericsт*et al.,* 2005, Van Den Berg *et al*., 2006;Travill, 2007, Anderson, 2009). Based on higher mean scores during each time-point measure, post-menarche girlsshowed advantages in muscle power during all three time points (p>0.05), although these differences were only ofsmall to medium practical significance (Table 4). Between T1 and T2 (Table 5) the throwing distance of post-menarche girls declined with -0.71m. This deterioration might be explained by anthropometric changes in the groupthat might have contributed to changes in body proportions and increases in fat percentage relative to musclepercentage during this period. During the same period the throwing distance of the pre-menarche group improved by+1.47m. A clear levelling off in power improvement was however seen in the post-menarche group which is also.According to researchers, muscle strength and by implication also muscle power development is influenced duringpuberty by various aspects including linear growth, body mass and muscle size (Gallahue*et al*., 2012; Grosset*et al*.,2008; De Ste Croix, 2007) which could either positively or negatively influence changes in power-related physicalfitness capabilities. De Ste Croix and co-workers (2003) report in this regard that muscle strength and power developlinearly from birth to puberty, reaching peak development at the same time as achieving peak height velocity (PHV)(average 12-years) and about 0.6 years after peak mass velocity (PMV). With the average onset of PHV and musclepower development relative to PHV as reported by researchers (De Ste Croix *et al*., 2013) in mind, our results agreewith current literature findings. This improvement contributed to the difference between the groups (2.56m)becoming smaller from T1 but still in favour of the post-menarche group. As more than 90% of the total group didreach menarche, including 46.2% of the pre-menarche group during the follow-up period of the study, hormonalchanges could subsequently influence both groups. Aspects other than hormonal changes could, however, beinfluential in these differences. In this regard, researchers reported that changes in body-segments (for example,shoulder girths and arm lengths) play a role in changing muscle power while changes in sitting height play asignificant role in changes in upper body chest and shoulder power between 14 and 16 years of age (Malina *et al*.,2004). Malina and co-workers (2004) further explain that girls tend to gain muscle power proportionally to bodysize before PHV, although after PHV, girls tend to increase less in bicep power proportionally to body size. Ourresults regarding muscle and fat percentage of the groups at T2 and T3 showed that, although pre-menarche girls hada higher percentage muscle mass (34.9%) and lower percentage fat mass (21.02%) compared to post-menarche girls'muscle mass (33.8%, p>0.05) and fat mass (25.84%, p<0.05) at T2, the post-menarche group still outperformed themin muscle power activities during the late stages of follow-up, although these differences between groups wereinsignificant. This advantage that the post-menarche group still displayed at T3, could possibly be ascribed to thetransfer of training effects in this group. Based on higher reported power levels in pre-menarche girls at younger agesin the current study, this might have provided them with more exposure to sport and coaching opportunities andconsequently contributed to improved power and neuromotor coordination to perform power-related activities(Williams & Reilly, 2000; Gallahue*et al*., 2012).

Regarding aerobic endurance, as measured in the number of shuttles completed, interaction effects (Figure 1a-c),as well as group differences over time (Table 4), were not significant. The interaction effects between the groupsover time in aerobic endurance, relative- and absolute $\dot{V}O^2$max was also not significant. Relative $\dot{V}O^2$max did, however,show a borderline significant group difference (F=3.25;p=0.07, Table 4). Differences between the groups in aerobicendurance were not statistically significant although differences increased slightly with increased age in favour of thepost-menarche group. However, when aerobic endurance was measured by means of $\dot{V}O^2$max, pre-menarche girlsshowed more favourable results in relative- and absolute $\dot{V}O^2$max at the completion of the study, especially with regardto relative $\dot{V}O^2$max. These difference at T3 was of practical significance only with regard to absolute $\dot{V}O^2$max. Currentresults agree with that of Van den Berg *et al.* (2006) who found in a cross-sectional analysis of female 14-year-oldtennis players, that late-developing girls performed better than early developing girls with regard to aerobicendurance, although the differences were also not significant. Only the increase from T2 to T3 was practicallysignificant (d>0.2) in aerobic endurance, although the increases over the follow-up period (T1-T3) were also ofpractical significance (d>0.2) in the post-menarche group (Table 5). This result could be explained by moreanthropometric, physiological and hormonal adaptive responses that would have taken place during this periodwithin the pre-menarche group. Such changes contributed to higher increases in percentage of fat mass (+5.24%, T2-T3) in the pre-menarche group compared to 3.13% in the post menarche group during the same period. Althoughpost-menarche girls still displayed the highest fat percentage at T3, they most probably have already adapted to their changed body composition while it might not have been the case in the pre-menarche group where large bodycomposition changes still take place which they might not yet have adapted to. Other influences such as heart rate variability might also have influenced the results. Armstrong *et al*. (1990) report in this regard that thelargest increase in heart rate occurs approximately one year before PHV in girls, which will have a direct positiveinfluence on the aerobic capacity and endurance of females. This might indicate that aerobic endurance is not onlyinfluenced byincreased mass and percentage body fat but by a combination of heart rate and stroke volume togetherwith changes in mass and percentage body fat (Armstrong *et al*., 1990). Aberberga-Augskalne and Kemper (2007)report that cardiovascular functioning in late-developing girls, show more effective patterns in terms ofcardiovascular responses to exercise, while Armstrong *et al.* (1990) reported no influences of maturity on aerobiccapacity/endurance response at maximal exercise among 12-year-old girls.

Our study, therefore, confirms that the level of maturation as assessed by means of menarche status does influencethe muscle power and aerobic endurance of girls, particularly during mid-adolescence and more specifically on apractical level. Earlier developing girls initially display advantages associated with earlier growth changes in power,and although they showed decreases in muscles power, they still showed advantages in muscle power at all time-points, T1-T3, although only on a practical level. Pre-menarche or late-developing girls displayed better aerobicendurance although of practical significance only. One reason for these differences were most probably the higherbody mass and fat mass of the post-menarche girls at T2 and Tt3. However, mass was identified as a confounder andthe results were adjusted accordingly, therefore, other influences which we were not able to investigate, could alsohave played a role. These findings are furthermore indicative that the period between 13-16 years of age should stillbe considered to be an unstable developmental period regarding changes in power and endurance levels of girls ofsimilar chronological ages but differing maturational ages. From the above findings, it can be concluded that thepower and endurance of girls if similar chronological ages can only be compared realistically after the influences ofmaturational development differences have been diminished which should be later than 15 years of age.

Despite the noteworthy findings of this study which mostly confirm the findings of previous studies in this regard,the study had limitations that need to be taken into consideration when interpreting the findings. Although the datawas collected over a follow-up period of two years, which strengthens the results of the study, the study was donelate in the pubertal development period. It therefore only focused on the period between 13 and 15 years of age,while a more substantial age-span period might be needed to investigate developmental differences over the fullpubertal phase. The data was also collected using a convenience sample where all the participants were from oneschool in theNorthwest Province of South Africa, resulted in small groups that could be compared which limits thegeneralization of the results. Although the school had hostel facilities which represented children coming fromvarious schools from the surrounding area groups were still small and our sample also did not evenly representmultiple racial groups and are mostly based on data of white (Caucasian) girls. No follow-up interviews were heldwith girls to verify that the datathat they have provided by means of the questionnaires were correct. Lastly, changesin environmental conditions such as weather conditions over the 3 years were out of the researchers' control andcould have influenced the performance of the participant on the day of testing. Consequently, it is recommended thatfuture research focus on a longer age span (10-18 years) including a larger, more generalizable study group.Furthermore, it is recommended that future studies collect data by means of questionnaires and interviews.

Conclusion

During mid-adolescence, at the mean ages between 13 and 15 years, girls of the same chronological age but differingmaturity status differ in their power and aerobic fitness, although differences are only of practical significance.Changes associated with maturation contributed to late maturing girls having overall more significant increases inmuscle power while the $\dot{V}O^2$max of post-menarche girls remained at a higher level between 13.51 and 15.51 years ofage. The findings confirm that age at menarche is a significant marker of power and endurance differences betweengirls especially at the age of 13 years. As seen from the current literature it is most likely the result of changes inhormonal levels, that drives anthropometric changes and changes in body composition, especially increases in bodymass, that seems to be the driving factor in levelling out maturational differences in girls of differing levels ofmaturity's power and endurance. It can, therefore, be argued that the time of reaching menarche is an unstabledevelopmental period for muscle power and aerobic endurance. The reaching of menarche provides advantages forpower development, but negatively influences the aerobic endurance of girls. Girls will consequently only behomogeneous in their power and aerobic endurance, 1-2 years after all girls of the same chronological age havereached menarche which will often only be around the age of 16 years. Therefore, our findings confirm that thepotential of girls to excel in sports based on power and endurance capabilities could only be accurately determinedmore than two years after all same-aged girls have reached menarche, especially in an age-based sport competitionstructure.

Information obtained by this study provided more insight into the magnitude of power and endurance changes thatoccur in girls after the onset of menarche and how it influences females of differing maturity status. This novelknowledge that shows practical significant differences between differing maturity groups is important as it can assistcoaches by incorporating this knowledge into training programs adapted for maturational differences betweenindividuals and groups. Furthermore, it can contribute to improved sports development and talent identificationprocesses, by providing an understanding of the temporary weaknesses but also strengths that are associated withearly or late development and by applying this knowledge in appropriate short- and long-term goals for girls thatparticipate in sport. More research is however recommended that should span over a longer developmental ageperiod, to obtain complete power and endurance fitness profiles of early and late maturing girls.

Conflict of interest

There are no conflict of interest relating to any of the authors.

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Author Contributions

All authors listed have worked together and gave the same input into the planning, writing, editing, and drafting ofthe paper.

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