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Original Article

Two-year follow-up on differences in anthropometric growth between pre-and post-menarcheal girls: implications for sport participation

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Abstract
Introduction: Puberty signifies developmental changes that differs in timing and tempo which contributes to noteworthy changes in stature, body composition, and the neuroendocrine axis. These changes, once again, directly influences the physical and motor abilities of girls, and consequently their performance in sport. **Methods**: This longitudinal study included a convenience sample where girls (n=58) aged 13.51±3.51 were divided by means of the Status Quo method, into a pre- (n=13) and post-menarche (n=45) group according to their menarche status. Anthropometric variables were measured, 4 months apart over 3 years and were analysed by means of a descriptive statistic and a repeated measures ANOVA with a Bonferoni post-hoc adjustment. **Results:** No significant chronological age-differences were found between the pre and post menarche groups at baseline. Both groups showed significant annual increases in all body measurements with the pre menarche group showing the highest 4 monthly increases and over time. However, the post-menarche girls stayed non significantly taller and heavier with longer body segments over the follow up period while this group also showed a higher BMI at a younger age. Group differences at baseline were mostly of statistical significance, also showing moderate to strong practical significance. Differences between the groups, however, declined to similar values two years later at 16.25 years, which signifies the end of the pubertal phase. The interaction effects over time were significant for all variable ($p<0.05$) except for leg-length ($p=0.81$). **Conclusion**: Maturational differences during adolescence did contribute to differences in anthropometric growth characteristics of girls. Timing differences in the onset of menarche results in temporary significant anthropometric growth differences, especially at younger ages. Early maturing girls have physiological advantages initially, but these benefits dissipate to more ideal body compositions among late maturing girls that will benefit them in sport at a later age. As differences in growth between early and late maturing girls declined to almost similar values at the end of the pubertal phase, these girls can only be compared realistically, regarding their potential for sport by the end of the pubertal phase at around the age of 16 years.
Key words: Puberty; Maturation; Adolescence; Menarche; Longitudinal.

Public interest statement

School sport is mostly age based, where date of birth is used to group children to compete against each other. However, biological age can differ considerably during the pubertal period. One marker of pubertal age is the onset of menarche which is associated with many physiological processes. Variation in the timing of menarche, results in early, average and late maturing girls. This paper investigated the extent of anthropometric differences between early- and late maturing girls and how these differences will consequently influence motor- and physical development. Significant anthropometric differences were found between early and late developing girls, especially at earlier ages, although these differences diminish over time. These influences are seen in differing body proportions, body segments, body composition, fat deposition and distribution, favouring the performance of early developers for a short period of time in sport. These developmental differences should be taken into consideration during sport selection and in developing programs.

Introduction

Adolescence, including the pubertal phase, is an important transition period between childhood and adulthood, accompanied by sexual maturation and physical growth (Sawyer *et al*., 2012). From a biological perspective, puberty in females is one of the most dynamic periods in life, producing changes in stature, body composition, and the neuroendocrine axis, as well as the achievement of fertility (Lee, Tsai & Lin, 2016). Puberty involves a series of developmental changes that differ in timing and tempo among individuals including

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a cascade of endocrine actions that contributes to noteworthy changes in growth (Eisenmann & Wickel, 2009). This in turn, influences performance based on physical and motor abilities (Hill, 2011).

Adolescence is documented to widely stretch between 10 and 25 years in girls (UNESCO, 2015; WHO, 2015a) and includes the pubertal phase. Girls enter the pubertal phase during early adolescence (11.8 to 13.0 years) (Malina, Bouchard & Bar-Or, 2004; Gluckman & Handson, 2006) when sexually transmitted glands become functional, and secondary sexual characteristics begin to develop. This period includes reaching menarche during late adolescence (Anderson, 2009). Menarche refers to the onset of the menstrual cycle, when a girl begins to ovulate for the first time (Towne, Czerwinski, Denarath, Blangero & Siervogel, 2005). Menarche is reached on average at the end of puberty (average 12.8 years) and about 6 months to 1 year after peak height velocity (Malina et al., 2004; Gluckman & Handson, 2006; Karapanou & Papadimitriou, 2010). The age at which menarche occurs, is not rigid and is influenced by a variety of factors, including genetic factors, nutrition, and health status (April-Sanders et al., 2021: Karim et al., 2021).

Achievement of menarche has been documented for decades due to its relation to various somatic, endocrine, and psychological manifestations (Marshall & Tanner, 1986). The most significant variation in sexual maturity (menarche, among others) among girls is found between the ages of 11 and 16 years, showing clear differences in anthropometric growth between early and late maturing girls, while also influencing physical and motor development (Van den Berg, Coetzee & Pienaar, 2006; Gluckman & Handson, 2006; Gerber, Pienaar & Kruger, 2021). This is due to significant hormonal changes that are taking place during the onset of menarche (Tanner & Davies, 1985; Vigil, 2016). Menarche is therefore an important milestone to take into consideration when analysing growth, physical- and motor fitness of girls during their pubertal period (Parent et al., 2003; Van den Berg et al., 2006; Gluckman & Handson, 2006; de Almeida-Neto, 2020). Measurements of stature are important for the evaluation of adolescents' growth, calculation of a nutritional index and the calculation and standardization of physiological characteristics such as lung volumes, muscle strength and basal metabolic rate (WHO, 2006).

Physical aging and differential timing of menarche from pre-pubertal age to adulthood represents a continuum that includes both early and late developers (Hoyt et al., 2020) The long-term effects of menarche occurring at an earlier or later age have for some time been a subject of research, related to sports participation (Apter, Reinila & Vihko, 1989; Forman et al., 1994; Pallavee & Rupal Sama, 2018), as it is important to consider biological maturation to correct for developmental differences. Some researchers agree that early, average, or late occurrence of maturity is associated with differences in anthropometric development, including more than just changes in longitudinal growth (Biro et al., 2001). Estrogen plays an important role in the lipogenic profile of girls during the puberty phase, especially after menarche (Rogol, Roemmich & Clark, 2002). Consequently, girls with a higher body mass index (BMI) and fat percentage tend to be more advanced in their maturation status compared to girls with a lower BMI and fat percentage (Biro *et al*., 2001; Gemelli, dos Santos & Souza, 2016). Decades ago, Deutsch and Mueller (1985) already indicated that girls, who reach menarche earlier, have a more central pattern of fat deposition compared to girls who reach menarche at a later age. In this regard Cumming, Sherar, Gammon, Standage and Malina (2012) report differences in BMI of up to 7.1 kg/m2 between early and late developers in the age group 13 to 14 years with the highest values found in early developers. Furthermore, Bronikowski and Bronikowak (2008) report longer lengths among early-developing girls compared to average and late developing girls at the age of 13 years with differences of 5 cm between maturity groups. Mass differences of 14.9 kg at age 12 years and 12.8 kg at 14 years are reported by Myburgh, Cumming, Silva, Cooke and Malina (2016) between females at different stages of development. Consequently, maturation and achieving of menarche plays an important role in the anthropometric growth and development of girls. Mirwald, Baxter-Jones, Bailey and Beunen (2001) are therefore of the opinion that it is important to link growth with an individual's maturation status during research or monitoring studies and furthermore bring this information into focus during sport participation and talent identification in girls.

Structural features such as body length, mass and limb lengths relate directly to the choice of a particular sport and also to the ability to perform in a particular position during team sports (Hill, 2011). Each individual and team sport requires a combination of health and motor (performance-related) fitness factors. In this regard researchers have found that early maturing girls are taller and heavier than late maturing girls during the early periods of puberty, although late maturing girls tend to catch up and surpass early maturing girls by having longer and leaner bodies with a preferable BMI (Malina et al., 2004). With regard to these changes in girls of differential maturation, AberbergaAugskalne and Kemper (2007) found in their longitudinal study of 45 girls from Riga between 7 and 16 years of age, that late developing girls (as determined by the age at PHV), showed more effective cardiovascular adjustments at each level of peak growth in response to exercise compared to early and average developers. Furthermore, although not reported for different maturity groups, Abbott and Collins (2002) found various correlations between anthropometric growth and physical fitness abilities in Scottish girls including correlations between the seated basketball throw and height, mass, sitting height and arm span, while the shuttle run (aerobic endurance) correlated only with stature and mass.

Validity of older studies focusing on girls' linear and secular growth are currently questioned for application on current populations due to secular growth and maturation changes that has taken place over the last few decades (Cole, 2003). This includes results showing a decline in the average onset age of menarche by 3 months every decade since the start of the twentieth century (Parent et al., 2006). Furthermore, only a few South-African studies focused on maturational growth (Monyeki et al., 2006; Richter, Norris, Yack & Cameron, 2007), although differences between early and late maturing girls were not the main focus in these analyses. Consequently, new and more current data, researched over a longitudinal period, is needed.

Therefore, this study aims to address this gap regarding differences in anthropometric growth of pre- and post-menarche girls, measured over a follow-up period of two years. Information about the timing of menarche, and its relation to different growth rates associated with this timing could be used in understanding if the magnitude of these growth differences will affect the physical and motor fitness development of girls in different stages of pubertal development. In this regard important information can be obtained regarding motor and physical fitness relative to menarche. Accordingly, this new knowledge could be used during the development of exercise and sports programmes to account for maturational differences between girls. Furthermore, it could be applied during talent selection to more accurately identify and develop girls who have the potential to excel in sport (Balyi & Way, 2010)

Methodology

Research design

This study has a longitudinal research design. The study project, "Growth and sport psychological characteristics of talented adolescents", was performed over three school years with follow-up measurements over a two-year period (2010-2012). The sample was based on a convenient and purposeful sampling of all grade 8 learners from one quintile 5 (quintile 1 = low socio-economic quintile, to quintile 5=high socio-economic) high school in Potchefstroom in the North-West Province of South-Africa. The data was collected by means of anthropometric, physical and motor tests as well as a status quo questionnaire. The anthropometric measurements took place 3 times per year, 4 months apart, with the physical and motor tests only measured once a year during the first measurements of each year (Feb). Baseline anthropometric measurements were taken in February 2010 and the final measurements took place in November 2012 accounting for nine time points of anthropometric measurements (T1-T9) in total.

Research group

Measurements took place from early 2010 until the end of 2012 (3 years), during which growth characteristics and physical and motor abilities were analysed. In 2010, 200 subjects (girls and boys) were enrolled in the study with a mean age of 13.58±0.25 years for boys (n=105) and 13.73±0.48 years for girls (n=95). Only girls formed part of this study. The final group of girls, who completed all follow-up measurements, consisted of 58 participants at a mean age of 16.26 years during the final measurements in 2012. The group were divided into a pre- (n=13) and post-menarche group (n=45) according to their menstrual status at baseline measurements. The loss of subjects over the study period was 37 girls (38%) from baseline measurements in February 2010 to the final measurements in November 2012 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 HREC Ethics Committee of the North-West University's Potchefstroom Campus (NWU 00142-11-A1) for the execution of the study. Permission for the project was also obtained from the principal of the school, the parents and each participant. All grade 8 learners whose parents provided permission and who gave consent themselves were subjected to the testing protocol.

Measuring instruments

Age at menarche

The age of menarche was determined by the status quo method (Żegleń et al., 2020) during February in 2010 (T1), 2011 (T4) and 2012 (T7) during the first measurements of each year. Girls had to indicate on the questionnaire by selecting YES or NO whether they have had their first menstrual cycle on or before the date of testing during the first measurements of each year in February. If they answered YES they also had to indicate the month and year when their first menstrual cycle took place.

Although the comparison of anthropometric and fitness characteristics of the group was done based on the baseline classification of pre- and post-menarche girls, the group's overall menarche status did change over the two-year period. From Table 2 it is clear that a high percentage of girls (77%) already reached menarche during baseline measurement (grade 8 - 2010) at a mean age of 13.51 years. Of these 77% who had reached menarche during baseline, 8% reached menarche during grade 5, 22% during grade 6, 66% during grade 7 and 2% during their grade 8 year. During the first follow-up measurements in grade 9 (2011), 91% of the group reached menarche at a mean age of 14.52 years with all but one girl (98%) reaching menarche at a mean age of 15.45 years during the last year of measurements (grade 10 - 2012).

Anthropometric measurements

The protocol as developed by the International Society for the Advancement of Kinanthropometry (ISAK) was used for stature and body mass measurements (Stewart, Marfell-Jones, Old & de Ridder, 2011). Sitting height was determined by a modified method (Simmons, 2000) and arm span according to the Canadian Sports for Life protocol (Balyi & Way, 2010). All researchers were trained level 2 Kinanthropometrists (theory and practical training), ranging from honours students to senior researchers in Kinderkinetics and Sport Science.

Furthermore, these researchers were equipped with all necessary skills and knowledge beforehand to perform these measurements. All measurements were taken behind enclosed spaces to ensure the privacy of the participants and were taken by researchers of the same gender as those of the participants. Participants had to wear minimal clothing during measurements.

Stature and Sitting height were measured to the nearest 0.1cm by means of a portable Harpenden stadiometer (Harpenden Holtain Ltd, Crymych, UK). Stature was measured with the subject standing, facing forward, with the heels, back and head against 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 0.1 cm. Two measurements were taken, of which an average value was used (Stewart et al., 2011). Inter-measurement reliability for stature was calculated as 0.98. ***Sitting height*** was measured by having the subject sit flat on the stadiometer with the back against the stadiometer and knees bent at about 90 degrees. The head of the subject was held in the Frankfort position by the examiner, and the measurement was taken to the nearest 0.1 cm while the subject had to inhale deeply (Simmons, 2000). ***Mas*****s** was measured by means of an electronically calibrated scale (Omro BF 511). The subject stood upright with weight evenly distributed over the scale with the arms at the sides of the body. The subject had to look straight forward while standing without shoes and as little clothing as possible and the measurement was then taken to the nearest 0.1 kg (Stewart et al., 2011). ***Arm span*** was measured by attaching a tape measure horizontally against a wall at about shoulder height of the subject with the starting point of the tape in a corner of a wall. The subject stood upright, with the front of the body and the toes against the wall. The arms had to be extended horizontally, with the palms facing the wall and the head turned to the left. The measurement was taken to the nearest 0.1 cm (Balyi & Way, 2010). ***Leg length*** was calculated by subtracting the sitting height value from the stature value. ***Sitting height ratio*** was calculated by using the following formula: Height/sitting height x 100. ***The body mass index (BMI)*** is a statistically developed equation developed by Adolphe Quetelet in the 1900's for evaluating body mass and is not related to gender and age. BMI was calculated by applying the following equation: Body weight in kilograms divided by height in meters squared or, BMI = x KG / (y M * y M) (x=body weight in KG, y=height in M).

Statistical analysis

The data was analysed by means of the "Statistica for Windows 2017" Statsoft computer programme package. For descriptive purposes, means, standard deviations (sd) and minimum and maximum values (StatSoft, 2017) were calculated. A repeated measures ANOVA was used to analyse changes in anthropometric variables over time with a Posthoc Bonferonni adjustment to determine statistical significance of differences between time point measurements. An independent T-test was also performed to investigate the differences in anthropometric characteristics between pre- and post-menarche girls with $p<0.05$ set as the level of significance. Effect sizes of differences were also calculated to determine practical significance of differences. The cut-off values of Cohen's d-value (Cohen, 1992) was used with a $d>0.2$=small effect size, $d>0.5$ (medium effect size) and $d>0.8$ (large effect size).

Results

Table 1 displays the descriptive characteristics of the group, including mean ages of pre- and post-menarche groups at baseline (Feb 2010), T4 (Feb 2011) and T7 (Feb 2012) during the 2-year follow-up period.

Table 1: Descriptive characteristics of the group and subdivided into a pre- and post-menarche group

	Year 1 (T1-3)		Year 2 (T4-6)		Year 3 (T7-9)	
	N	**Mean age±SD**	**N**	**Mean age+SD**	**N**	**Mean age+SD**
Group	58	(T1)13.51±3.5	58	(T4) 14.51±3.51	58	(T7) 15.51±3.51
		(T3) 14.26±3.5		(T6) 15.26±3.51		(T9) 16.26±3.51
Pre-menarche	13	(T1) 13.52±3.58	13	(T4) 14.52±3.58	13	(T7) 15.52±3.58
		(T3) 14.27±3.58		(T6) 15.27±3.58		(T9) 16.27±3.58
Post-menarche	45	(T1) 13.51±3.53	45	(T4) 14.51±3.53	45	(T7) 15.51±3.53
		(T3) 14.26±3.53		(T6) 15.26±3.53		(T9) 16.26±3.53

T1=Year one (grade 8); T4=Year 2 (grade 9); T7=Year 3 (grade 10); N=number of participants; M=Mean age

At baseline (T1), 58 girls completed all measurements, and were then classified into 2 groups according to their menarcheal status, namely pre-menarche (n=13, 23%) and post-menarche girls (n=45, 77%). Of the pre-menarche group (n=13) who were not menarcheal during baseline, 12 reached menarche in the following years, of which eleven at T4 and another one at T7, in February of each new school year. The group had a mean age of 13.51 years at baseline with no significant age differences (0.01 years) between the pre- and post-menarche groups. All follow-up comparisons between the groups were done based on the baseline grouping.

Three time point measurements, 4 months apart, took place during each year including T1-T3 during year one (2010, grade 8) starting at a mean age of 13.51 years, T4-T6 during year two (2011, grade 9) starting at a mean age of 14.51 years and T7-T9 in year three (2012, grade 10) starting at a mean age of 15.51 years and ending at a mean age of 16.26 years (T9). This contributed to 2-year follow-up measurements of 9 time point measures, 4 months apart, taken over a three year school period.

Table 2 reports the descriptive anthropometric characteristics that were obtained at each of the 9 time points of the pre- and post-menarche groups, and significance of differences between the groups during each time point measure and over time. Measurements included stature, arm span, mass, sitting height, sitting height ratio, leg length and BMI. Table 3 displays the mean 4-monthly changes in anthropometric characteristics as well as annual changes over the 2-year follow-up period (T1-T4, T4-T7, T7-T9 and T1-T9), as well as statistical and practical significance of these changes. Changes over the follow-up period are also displayed in figure 1 a-g for each of the growth characteristics. It is important to note that for arm span, sitting height, sitting height ratio and leg length, no measurements were available for T2.

The repeated measures ANOVA analysis showed significant interactions between the groups over time regarding stature, arm span, mass, sitting height, leg length and BMI, as displayed in Fig. 1 a-g. The groups also differed significantly over time in the same variables, except for leg length (p<0.05, Table 2). A comparison of time point differences between the groups showed that the post-menarche group (n=45) was on average the taller and heavier group at baseline (T1) with longer upper limbs (p<0.09, d=0.48) and lower limbs (p=0.39, d=0.24), although pre-menarche girls had a lower BMI value (p=0.06, d=0.60). Differences of 4.76 cm (stature), 4.05 cm (arm span), 8.54 kg (mass), 2.87 cm (sitting height), 1.32 cm (leg length) and 2.2 (BMI) were all significant (p<0.05) between pre- and post-menarche girls during T1. Only the sitting height ratio (0.27%) was not statistically or practically significant at T1 (Table 2). Statistical significant differences were only found in the first year of the study between the groups (grade 8 year, T1-T3), after which differences became mostly statistical insignificant only showing differences of 0.03cm (stature), 0.29cm (arm span), 2.61kg (mass), 0.54cm (sitting height), 0.08cm (leg length), 0.26% (sitting height ratio) and 1.04 (BMI) between the pre- and post-menarche girls during T9 (Table 2).

Table 2: Descriptive statistics and significance of group and time differences of anthropometric characteristics over the follow-up period (t1-t9)

	Pre-menarche n=13			Post-menarche n=45			Between groups		Over time T1-T9	
	M ± SD	Min	Max	M± SD	Min	Max	p	d-	F	p
				Stature					**56.92**	**>0.01***
T1	156.89±8.99	147.60	177.60	161.65±6.48	144.60	174.90	0.03*	0.60$^{\#\#}$		
T2	159.20±8.88	150.10	179.40	163.27±6.64	146.90	177.00	0.07$^{\cdot}$	0.50$^{\#\#}$		
T3	161.16±8.62	150.40	180.40	163.99±6.61	147.50	177.90	0.20	0.36$^{\#}$		
T4	162.30±8.61	151.70	180.80	164.41±6.68	147.50	178.30	0.35	0.27$^{\#}$		
T5	162.96±8.58	152.00	181.10	164.50±6.73	147.60	179.00	0.49	0.19		
T6	164.30±9.03	152.90	182.70	165.04±6.63	147.60	179.30	0.74	0.09		
T7	164.65±8.90	152.90	182.70	165.16±6.61	148.15	179.30	0.82	0.06		
T8	165.01±8.90	152.90	182.70	165.48±6.56	149.80	179.30	0.83	0.06		
T9	165.75±8.80	153.90	182.80	165.78±6.63	149.80	179.50	0.98	0.01		
				Arm span					**37.84**	**>0.01***
T1	158.91±9.38	146.90	179.50	162.96±7.03	146.10	178.60	0.09$^{\cdot}$	0.48$^{\#}$		
T3	162.13±9.88	147.50	182.30	165.02±7.21	146.80	183.20	0.24	0.33$^{\#}$		
T4	163.57±10.66	147.50	183.60	165.67±7.42	146.80	184.00	0.42	0.22$^{\#}$		
T5	165.24±10.25	150.40	186.00	166.48±7.30	148.50	184.30	0.62	0.13		
T6	166.34±10.65	150.40	186.00	166.84±7.51	148.50	185.80	0.85	0.27$^{\#}$		
T7	167.20±10.60	151.30	186.30	167.68±7.45	148.60	185.80	0.85	0.05		
T8	167.63±10.75	151.50	186.50	167.80±7.50	148.60	185.90	0.94	0.02		
T9	168.41±11.20	151.50	188.90	168.12±7.61	148.70	185.90	0.91	0.03		
				Mass					**14.69**	**>0.01***
T1	48.36±10.04	38.10	65.20	56.90±9.42	43.60	81.60	0.01*	0.91$^{\#\#\#}$		
T2	51.93±10.68	40.40	70.10	59.62±9.41	44.80	82.20	0.01*	0.49$^{\#\#}$		
T3	53.31±11.44	40.70	76.50	59.17±9.45	46.20	79.80	0.06$^{\cdot}$	0.55$^{\#\#}$		
T4	55.63±12.73	42.60	79.30	60.46±9.62	46.80	82.00	0.14	0.42$^{\#}$		
T5	57.43±12.28	44.60	80.20	62.01±9.75	48.90	84.70	0.16	0.41$^{\#}$		
T6	58.23±11.75	46.10	80.80	61.72±9.39	48.30	83.60	0.27	0.32$^{\#}$		
T7	58.79±12.22	45.15	82.35	61.11±8.82	48.35	81.00	0.45	0.21$^{\#}$		
T8	61.00±11.55	47.90	85.90	63.14±8.95	48.70	83.40	0.48	0.20$^{\#}$		
T9	59.78±11.64	46.00	81.80	62.39±9.55	47.40	85.90	0.41	0.24$^{\#}$		
				Sitting height					**17.72**	**>0.01***
T1	79.51±3.45	75.40	87.20	82.38±3.27	73.80	89.60	0.01*	0.85$^{\#\#\#}$		
T3	82.09±3.07	77.90	88.50	83.76±3.59	75.30	92.00	0.13	0.50$^{\#\#}$		
T4	83.01±3.11	78.50	89.40	84.22±3.55	75.60	92.00	0.27	0.36$^{\#}$		
T5	83.94±3.04	79.20	90.00	85.05±3.53	76.60	92.80	0.30	0.33$^{\#}$		
T6	84.66±3.05	79.90	91.30	85.46±3.45	76.60	93.50	0.44	0.24$^{\#}$		
T7	85.12±2.82	81.00	91.40	85.73±3.47	76.70	93.50	0.56	0.19		

T8	85.63±2.55	81.70	91.40	86.19±3.59	77.70	93.50	0.60	0.18		
T9	85.92±2.64	81.70	92.00	86.46±3.59	78.10	93.90	0.61	0.17		
				Sitting height ratio					**17.62**	**>0.01***
T1	50.72±1.32	48.80	52.84	50.98±1.42	48.25	53.94	0.57	0.18		
T3	50.99±1.73	48.43	54.11	51.08±1.44	48.08	54.44	0.84	0.05		
T4	51.20±1.64	48.63	53.77	51.24±1.39	48.57	54.57	0.93	0.26#		
T5	51.56±1.50	49.29	53.77	51.71±1.214	49.43	54.60	0.71	0.10		
T6	51.58±1.55	49.03	54.33	51.79±1.19	49.32	54.60	0.60	0.15		
T7	51.76±1.52	49.19	54.34	51.91±1.23	49.32	54.58	0.69	0.10		
T8	51.96±1.55	49.19	54.34	52.09±1.26	49.29	54.77	0.75	0.09		
T9	51.90±1.55	49.08	54.24	52.16±1.20	49.73	54.84	0.51	0.18		
				Leg length					**0.05**	**0.81**
T1	77.86	70.20	91.80	79.18	66.90	86.60	0.39	0.24#		
T3	78.85	70.30	91.90	79.40	66.90	86.60	0.72	0.09		
T4	79.19	70.90	91.90	79.55	67.00	86.80	0.81	0.06		
T5	79.25	71.10	91.90	79.65	67.00	86.80	0.79	0.07		
T6	79.58	71.10	91.90	79.78	67.00	86.90	0.90	0.03		
T7	79.78	71.20	92	79.86	67.55	86.90	0.96	0.01		
T8	79.89	71.30	92.3	79.98	68.90	87.00	0.95	0.01		
T9	80.17	71.30	92.8	80.09	68.90	87.00	0.95	0.01		
				BMI					**4.67**	**0.03***
T1	19.59±3.50	16.59	26.79	21.79±3.73	16.79	39.02	0.06‣	0.60##		
T2	20.41±3.49	17.10	27.76	22.37±3.52	17.57	38.09	0.08‣	0.55##		
T3	20.43±3.68	17.11	29.18	22.00±3.36	17.60	35.99	0.15	0.44#		
T4	21.02±4.07	17.50	29.88	22.36±3.36	17.54	36.53	0.23	0.35#		
T5	21.56±3.86	18.14	29.81	22.98±3.52	18.64	38.51	0.21	0.38#		
T6	21.43±3.67	18.37	29.46	22.65±3.24	18.35	36.22	0.25	0.35#		
T7	21.65±3.78	18.08	30.02	22.49±2.91	18.80	33.91	0.39	0.25#		
T8	22.37±3.46	19.58	31.06	23.11±3.04	18.35	35.27	0.45	0.22#		
T9	21.68±3.49	18.55	29.75	22.72±3.25	18.29	36.09	0.31	0.30#		

n=Number of participants; T1-T3= year 1 (grade 8); T4-T6=Time point measurements after 12 months (grade 9); T7-T9=Time point measurement after 24 months (grade 10); M=Mean; SD=Standard deviation, Min=Minimum value of group; Max=Maximum value of group; *=Statistical significance (p<0.05); ‣=Borderline statistical significance (p<0.10) #=small effect size (d<0.2); ##=medium effect size (d<0.5); ###=large effect size (d<0.8)

Differences were, however, still of small practical significance up to the end of the second year (T1-T6). This is mainly due to pre-menarche girls having the most significant changes during 4-monthly measurements in all anthropometric characteristics throughout the follow-up period as are evident from the results displayed in Table 3 for pre- and post-menarche girls respectively. The most significant increases of 5.41 cm/2.76 cm (stature), 4.66 cm/2.71 cm (arm span), 7.27 kg/3.57 kg (mass), 3.50 cm/1.84 cm (sitting height), 1.33 cm/0.37 cm (leg length) and 1.43/0.57 (BMI) were found during T1-T4. Sitting height ratio increased most during T4-T7 (14.51-15.51 years). Post-menarche girls' growth in stature and arm span started to reach a plateau from T4-T9 with pre-menarche girls only reaching this plateau effect at around T6, approximately 1 year after post-menarche girls.

During the final measurements (T9), post-menarche girls still displayed taller, heavier and longer sitting heights although on a non-significant level (p>0.05, d=0.17). The arm span of pre-menarche girls were slightly longer than post-menarche girls during T9 (p=0.91, Table 2). Changes in stature co-exist with changes of body segments. Post-menarche girls had the longest upper bodies (sitting height) with a baseline group difference of 2.87 cm (T1), although the difference of 0.54 cm became smaller and insignificant at T9 (Table 2, Figure 1d). Sitting height of both pre- (3.50 cm) and post-menarche (1.84 cm) girls increased most significantly between T1-T4 (Table 3). Although only a few significant 4-monthly increases were found, the upper body segments of both groups only showed a few statistical significant 4-monthly changes. Annual increases and also increases over the 3-year school period were, however, statistically significant in both groups. The pre-menarche group showed a bigger annual increase during all measurements accounting for a bigger increase in sitting height of 2.32 cm over the follow-up period. Both pre- and post-menarche girls had a late increase in sitting height between T7-T8, influencing their sitting height ratio that also showed a late increase during the same period.

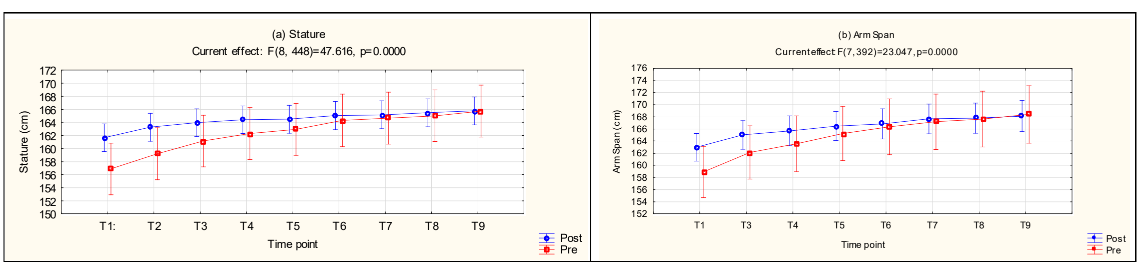
Leg length, on the other hand, showed small, gradual and non-significant 4-monthly increases throughout the study (Table 2) in both groups. It therefore seemed that body stature was influenced more by increases of the upper body (sitting height) over the follow-up period. Although the post-menarche group on average were taller in stature and for most of the study until T8 had a longer arm span than the pre-menarche group, the tallest individual as well as the individual with the longest arm span was from the pre-menarche group. Mass showed a similar developmental curve to stature, although mass showed time periods of decline which were also more evident in the post-menarche group, and, similar to stature, not all annual increases in mass were significant

(Table 3). Furthermore, mass and BMI showed similar growth curves as BMI is influenced by changes in mass. Post-menarche girls were the heavier group throughout the study, although differences between the groups (8.54 kg at T1, p=0.01, d=0.91 and 2.61 kg at T9, p=0.41, d=0.24), became smaller and less significant with increasing age (Table 2, Figure 1c). These smaller differences between the groups are attributed to higher increases in mass in pre-menarche girls over the T1-T9 period (11.41 kg vs 4.91 kg, Table 3). Four-monthly increases were however, only significant (p<0.05) between T1 and T2 in the pre- (3.56 kg) and post-menarche group (2.72 kg) and borderline at T3 (p=0.06), with both groups experiencing one further significant increase between T7-T8. The largest changes in mass occurred between T1-T4 (7.27 kg) and T4-T7 (3.16 kg) in the pre-menarche group (p<0.05) with the post-menarche group only showing a small, but significant increase in mass between T1-T4 of 3.57 kg. Declines in mass were also seen, but mostly in the post-menarche group between T2 and T3, T5 and T7 and T8 and T9, while pre-menarche girls only showed one decline between T7 and T8 (Table 3). Changes in mass seemed to reach a plateau between T4-T7, although a large significant increase was found between T7 and T8 with a decrease between T8 and T9 in both groups. These changes in mass also resulted in similar, larger than usual, changes in BMI during the same periods. Differences in BMI were borderline at T1 and T2 with the pre-menarche group showing the biggest increase of 2.08 kg/m2 from T7-T9, ending with a similar, although still lower BMI to the post-menarche group at T9 (Tables 2 and 3, Figure 1g).

Table 3: Statistical and practical significance of changes between time points (4-monthly and annual) in anthropometric characteristics of pre- and post menarcheal girls

	T1-T2	T2-T3	T3-T4	T4-T5	T5-T6	T6-T7	T7-T8	T8-T9	T1-4	T4-7	T7-9	T1-9
Stature (cm)												
Pre-menarche	2.30*	1.96*	1.13*	0.66	1.34*	0.35	0.35	0.73	5.41*	2.35*	1.10*	8.86*
Post-menarche	1.63*	0.75*	0.42	0.14	0.53	0.12	0.32	0.30	2.76*	0.75*	0.62*	4.12*
Arm span (cm)												
Pre-menarche	#3.21*		1.44*	1.66*	1.10*	0.85*	0.43	0.77*	4.66*	3.63*	1.21*	9.50*
Post-menarche	#2.05*		0.65*	0.80*	0.35	0.84*	0.12	0.32	2.71*	2.01*	0.44*	5.16*
Mass (kg)												
Pre-menarche	3.56*	1.37	2.32	1.79	0.80	0.56	2.20*	-1.21	7.27*	3.16*	0.99	11.41*
Post-menarche	2.72*	-0.45	1.29	1.54	-0.29	-0.61	2.03*	-0.75	3.57*	0.65	1.28	4.93*
Sitting height (cm)												
Pre-menarche	#2.57*		0.93	0.93	0.71	0.46	0.51	0.28	3.50*	2.11*	0.80	6.40*
Post-menarche	#1.38*		0.47	0.83*	0.43	0.26	0.46	0.27	1.84*	1.51*	0.73*	4.08*
Sitting height ratio (%)												
Pre-menarche	#2.57		0.92	0.93	0.71	0.46	0.51	0.28	0.48	0.56	0.14	6.40*
Post-menarche	#1.38		0.46*	0.83*	0.41	0.26	0.46	0.26	0.26	0.67*	0.25	4.08*
Leg length (cm)												
Pre-menarche	#0.99*		0.33	0.06	0.33	0.20	0.10	0.28	1.33*	0.59*	0.39	2.31*
Post-menarche	#0.22		0.15	0.09	0.12	0.08	0.12	0.10	0.37*	0.30*	0.23	0.91*
BMI (L/m^2)												
Pre-menarche	0.82	0.02	0.58	0.54	-0.13	0.22	0.71	-0.69	1.43	0.63	0.03	2.08*
Post-menarche	0.58	-0.37	0.36	0.61	-0.33	-0.15	0.61	-0.38	0.57	0.13	0.23	0.93*

T1-3=grade 8 measurements; T4-6=grade 9 measurements; T7-9=grade 9 measurements; *=Statistical significant (p>0.05); 3=No measurements for T2



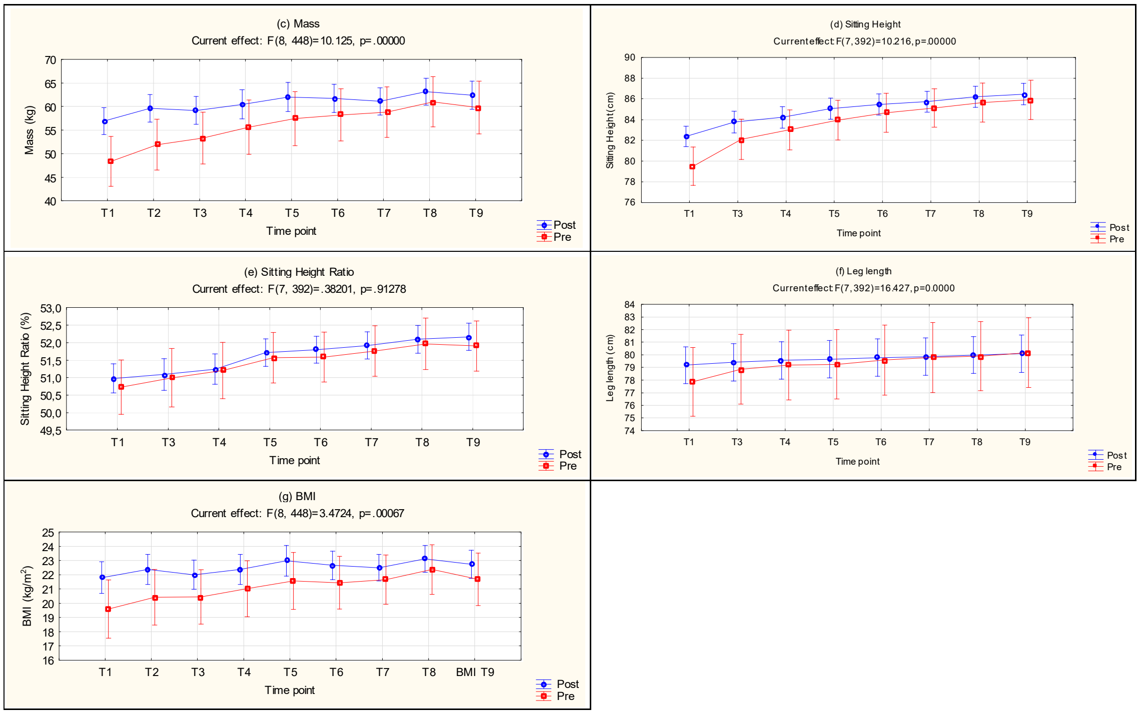


Figure 1 (a-f): Growth curves of pre- and post-menarche girls' anthropometric characteristics
Vertical bars denote 0.95 confidence intervals; T1-T3=grade 8; T4-T6=grade 9; T7-T9=grade

Discussion

The objective of this study was to investigate over a 2-year follow-up period if anthropometric growth differs between girls of differing menarche status between the ages of 13 to 16 years. This was done by comparing differences in growth characteristics of pre- and post-menarche girls over 2 years in 4-monthly increments based on their menarcheal status. Seventy seven percent (n=45) of the group have reached menarche before the mean age of 13.51 years (T1), 95% (n=53) during grade 9 (T4) and almost all (98%, n=57) during their grade 10 year (T7) before reaching the mean age of 15.51 years (Table 1). All comparisons were done based on menarcheal status at T1, dividing the group into 13 pre-menarche and 45 post-menarche girls. The cut-offs for normal menarcheal onset as published by Malina et al. (2004) [early- (<11.8 years), average- (11.8-13.8 years) and late (> 13.8 years) maturing girls], indicate that most of the group can be categorized as average developing girls.

Overall, the results are in agreement with most studies that report differences in growth between girls of differing menarcheal status (Biro et al., 2001l; Malina et al., 2004; AberbergaAugskalne & Kemper, 2007). At baseline, at a mean age of 13.51 years, post-menarche girls were statistically and practically significantly taller ($p<0.05$, $d=0.60$) and heavier ($p<0.05$, $d=0.91$) with longer body-segments (sitting height and arm span) in comparison to the pre-menarche group. Significant differences of 4.76 cm (stature), 8.54 kg (mass), 4.05 cm (arm span), 2.87 cm (sitting height), 0.26 (sitting height ratio) and 2.20 in BMI between the pre- and post-menarche girls were found (Table 2), confirming that reaching menarche earlier, influences anthropometric growth in girls. These differences were also significant over time, although it became smaller and showed less significant time point differences with increasing age from T2 onwards. Differences decreased at T4 (first measurement of follow-up year) to 2.02 cm (stature), 6.09 kg (mass), 2.60 cm (arm span), 1.21 cm (sitting height), 0.04% (sitting height ratio) and 1.34 (BMI), showing no statistical significance ($p>0.05$), although all differences at this age were still of practical significance with mass differences ($d=0.42$) being the most significant (Table 2). These declines in differences with increasing age among early and late maturing girls, between the ages of 13 and 16 years, are in agreement with Bronikowski and Bronikowska (2008) who also report declines in differences, to similar results between early and late maturing girls and ascribed these results to this period being most affected by pubertal and maturational changes. Although pre-menarche girls showed lower mean values in all the anthropometric characteristics, they had bigger 4-monthly, as well as annual increases, in all growth characteristics in comparison to the post-menarche group. This coincides with Biro et al. (2001) who stated that although late developing girls grow less at a younger age; their final stature is longer compared to average or early developing girls. Although this is not yet evident in the findings during the final measurements at 16.26 years, stature in particular showed resemblance with differences less than 1cm ($p>0.05$) from T6 onwards and final stature measures of 165.75 cm (pre) and 165.78 cm (post) during T9 (Table 2). As the post-menarche group was in their final stages of increasing stature as they only grew 4 cm over the 9 time point measures compared to 8 cm in the pre-menarche group, it is expected that the pre-menarche group will surpass them in most anthropometric characteristics with a further increase in age. Researchers report in this reg]ard that late maturing girls surpass early maturing girls around the age of 15 years of age (Biro et al., 2001; Malina et al., 2004). In agreement with these findings, based on minimum and maximum values, the pre-menarche group included girls that were the tallest from T1-T9 and heaviest during T7-T9 (last year of the study) (Table 2).

The bigger increases in growth characteristics seen in the pre-menarche group can be ascribed to the maturational affects that are associated with reaching the age of menarche, occurring late in the growth spurt phase (6 to 12 months after PHV), and which have a big influence on pre-menarche girls' growth at that age. According to Pearson et al. (2006) height and weight increases are primarily the result of increased hormone secretion, which is the highest during the onset of menarche, and therefore, linear growth are strongly associated with menarche status at the later end of the pubertal phase. Armstrong and McManus (2000) indicate that during the growth acceleration phase, which lasts 3 years, girls approximately grow 6-8-6 cm respectively and reach PHV at approximately 11.9 years. According to these statistics the post-menarche girls have already surpassed PHV as their maximum increase in stature was only 2.71 cm from T1-T4. The pre-menarche girls were probably in their last year of the growth acceleration phase during the same period with an annual increase of 5.41 cm from T1-T4, after which a levelling out in growth was also evident in this group in year 2 (2.35 cm) and year 3 (1.10 cm). These results also coincide with results from AberbergaAugskalne and Kemper (2007) finding that although early developing girls have larger PHV increases of 9.4±1.7 cm in comparison to average- (8.2±2.2 cm) and late developers (7.2±1.9 cm), late developing girls on average has a longer growth period and as a result have a taller final stature. Furthermore, due to late developing girls reaching PHV almost 2 years later than early developing girls, they have 1 to 2 years longer of annual growth of approximately 5 cm/year (Malina et al., 2004). This is also confirmed by the results displayed in Table 3, where most statistically significant and also largest differences between 4-monthly measurements were found in the pre-menarche girls. Moreover, in terms of differences between measurements, it can be concluded that although these differences were statistically significant, increases in stature and arm span levelled out during T7-9. This is indicative of the pre-menarche group reaching the end of their growth spurt at around 15 to16 years of age, almost 2 years later than the post-menarche group providing them with an additional 2 years of growth before entering their growth spurt. Sitting height also showed a statistically significant change during this period (T7-T9) in the post-menarche group, although differences between the groups still grew smaller. This is probably due to sitting height being in the final stages of development, which in turn affects stature increases at a later stage (Malina et al., 2004).

Regarding overall growth patterns (Table 3, Figure 1), it can be seen that late developing girls (pre-menarche) had a longer period of growth before reaching a plateau (Table 3). These girls also experienced a period of maximum growth in stature from T1-T6 with final significant ($p<0.05$) increases in stature between T5 and T6, hereafter they reached a plateau from T6 onwards. Further, maximum increases in stature (T1-T6) also coincide with increasing mass between T1 and T5. These changes, however, did not have a significant effect on pre-menarche girls' BMI as both mass and stature increased. Even so, this was not the case with increased age where changes in stature declined, but changes in mass did not (T7-T9 in pre-menarche girls) and as a result had the biggest effect on changes in BMI during this period (Table 3). In the same context post-menarche girls showed small changes in stature during the same period while reaching a plateau as early as T4 onwards with their last significant increase between T1 and T3. This resulted in post-menarche girls' mass already influencing their BMI from an earlier age (T1, 13.51 years). Sitting height ratio did not show statistical or practical significance differences during this phase. Once again this could be due to sitting height reaching peak development at a stage later than that of stature (Malina et al., 2004). No statistically significant group differences were found from T3 onwards in sitting height. A high once-off increase in mass was however seen in both the pre- (2.20 kg) and post-menarche (2.03 kg) group between T7-T8 also largely affecting their BMI during the same period. This increasing phenomenon in both groups are probably not a growth-related increase but rather lifestyle related as it co-occurred just after a summer holiday period that fell between T6 and T7 that could have influenced their body-composition. Decreases in mass were again seen afterwards due to participation in sport and recreational activities at the start of the new year.

.Practical implications of maturational differences for sport performance

The anthropometric growth differences that were found in this study can influence performance based on motor and fitness abilities (Hill 2011).

Mid-adolescence, and more specifically the time period just before and after reaching menarche, is described as a vulnerable period in the development of physical and motor skills due to the significant changes that occur in body segments and body dimensions during this period.-(Gaudineau et al., 2010). Increased stature, changes in upper and lower body dimensions and longer limbs, together with the development of more muscles mass, will be conducive in producing more power and strength and consequently contributing to higher performance outputs (Malina et al., 2004). However, increasing body mass and the distribution of fat in certain areas of the body, can influence the gravitational point of the body (Pereira et al., 2017), influencing locomotor skills and in turn, speed and agility. A study on 14-year-old adolescent girls from Western Australia confirmed small, but negative correlations between BMI (p=-0.13), agility and muscle endurance (p=-0.27), with positive correlations between BMI and aerobic fitness (p=0.27) and muscle strength (p=0.15) (Hands, Larkin, Parker, Straker & Perry, 2008). Abbott and Collins (2002) also reported various correlations between anthropometric

characteristics and fitness measures in 1217 Scottish girls with a mean age of 12.68 years. The over-head throw, and vertical jump correlated positively with stature; agility correlated negatively with mass, while sitting height and speed correlated positively with height and negatively with mass.
The rate at which an action can be performed will also be influenced by stature and mass of the body and the specific limb lengths involved in the action. Our results indicate that early developing girls were significantly longer, with longer arm spans, higher mass and sitting heights at 13.51 years ($p<0.05$), although differences levelled out over the follow-up period to not being statistically or practically significant at T9 (16.25 years). Hill (2011) indicates in this regard that a tennis player with longer arms will generate more speed and rotation on the ball due to the longer levers at their disposal, compared to players with shorter arms. Stature can, however, also be detrimental where a lower gravity point is needed for an agile motion, such as during a rapid movement of the centre in netball. Mass also influences sports performance, as a larger and heavier player with a higher fat mass will have a reduced mobility and range of motion, although increased muscle tissue can possibly contribute to a person's strength and power outputs (Malina et al., 2004). Sitting height will also affect the performance of specific sports skills, as reported by Visnapuu and Jūrimäe (2008). They found that the upper body strength in 14 to 15-year-old handball players was dependent on sitting height.
These anthropometric influences also have implications for sport selection. Williams and Reilly (2000) state in this regard that players chosen for individual, or team sports are initially chosen (before the onset of puberty and menarche) based on physical characteristics. This results in inadequate opportunities for late developing girls to develop and excel in sport due to their current insufficient physical characteristics. In agreement, Van den Berg et al. (2012) also concluded that the physiological development of late developers, which had not yet fully developed, can lead to the elimination of talented players at a young age during the talent identification process. It is therefore important for sport administrators to take note of these early and late maturation influences on sport performance, especially during the ages when all girls have not been fully exposed to the effects of puberty and menarche. Knowledge of these timing differences is especially important to identify girls more accurately with the potential to excel in sport.

Although the data were collected over a two-year follow-up period, strengthens the results of the study, the study still had shortcomings that must be kept in mind. The sample was collected by means of convenience and did not have an even representation of the demographics of the South African population as it mainly included white girls. Environmental conditions such as adverse hot or cold weather conditions were not identical over the 2-year period and could have influenced the results. All participants were from one school in the North-West Province of South Africa, although the school had hostel facilities with children from 46 primary schools' representative from the surrounding area, making the results more generalizable. The study only included data of girls between 13 and 15 years of age, which is a period that is quite late in the pubertal development of girls. Consequently, a larger age period including 11 to 16 years of age is needed to fully investigate influences of the pubertal phase. Further research is therefore recommended that include a longer developmental period and a larger and more representative group of participants to obtain a more complete understanding of the influences of developmental growth and physical fitness profile.

Conclusion

This study confirmed that the timing of the onset of the menstrual cycle significantly influence the tempo of anthropometric growth of girls. This includes changes in body proportions, body segments and body composition, and fat deposition and distribution as was evident in the differing BMI levels. Differences between pre- and post-menarche groups were the highest in grade 8 at the age of 13.51 years, while these differences were mostly levelled out by the age of 16 years. Early maturing girls were taller and heavier at a younger age and had longer body segments such as arm spans and sitting heights. These differences relating to body segment proportions may contribute to discrepancies in sport performance between early and late developing girls. It is concluded that the influence of growth between early and late maturing girls evens around 16 years of age.

Information obtained during this study provided more insight into the timing and rate of biological and physiological changes occurring in girls of different maturing levels during mid-adolescence, and the impact of these changes on aspects such as physical and motor performance. This knowledge may aid the better understanding of the effects of differential timing of menarche on changes in anthropometric characteristics which are also valuable in the understanding of a girl's progression to adult growth characteristics. This information may therefore aid coaches and other sport administrators in better predicting which girls have the most preferable anthropometric characteristics to excel in sport. As differences in growth between early and late maturing girls declined to almost similar values by the end of the pubertal phase in the study, the findings suggest that girls can only be compared realistically and classified as potential talented sport stars by the end of the pubertal phase at around age 16 years of age.

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Conflict of interest

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

Author contributions

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

Authors summary

Barry Gerber and Anita Pienaar's research interest focus on longitudinal analysis of health, growth, physical activity and fitness in children and adolescents, affordances of motor development and motor proficiency in children and improvement of motor problems in children with differing special needs, aged 0-13 years. Ankebé Kruger's research interests focus on sport and performance psychology. More specifically her focus is on the the relationship between sport participant's levels of mental skills and sport performance and lastly on mental health and cognitive performance of athletes and the association with performance in sport. This study covers the complex interactions between growth, maturation and development during adolescence, more specifically the effect of individual variation in the state and development of physical- and motor capabilities during adolescence in girls.

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