Comparison of sitting height protocols used for the prediction of somatic maturation

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Somatic Maturation | Methods | Sitting Height

Headline

Biological maturation represents human growth and development and is known to confound talent identification in youth sport. Relatively early maturing athletes are often favoured for selection (1), perhaps owing to their enhanced physical qualities (2,3). This may preclude later developing youth athletes with equal, or even greater, potential to emerge from talent development systems.

There are implementation challenges associated with criterion methods of determining biological maturation. Accordingly, non-invasive algorithms have been developed from somatic growth measures (4-6) to estimate the age an athlete experiences the adolescent growth spurt (age at peak height velocity [APHV]). Cost and limited portability present barriers to using the criterion measure of sitting height, a sitting height stadiometer, in youth sport. Hence, many users of maturity offset algorithms do not utilize this apparatus (3,7). It is presently unclear what impact different sitting height measurement techniques may have on predicted APHV.

Aim

Erroneous APHV estimations may have implications for both talent and athletic development processes. Therefore, the primary purpose of this report was to examine the reliability and validity of different sitting height protocols used in research and applied practice. We also took the opportunity to compare these measurement properties when the anthropometric measures were imputed into the different maturity offset algorithms available in the literature to date (4-6).

Methods

With ethical approval (H11985) and parental assent, 38 male (age: 14.1 ± 1.1 years) and 54 female (age: 14.2 ± 1.4 years) sports high school students participated in the study. Students were drawn from elite development programs in Soccer (n = 54), Netball (n = 19), Athletics (n= 9), Rugby Union (n = 9) and Basketball (n = 1), attending a specialist school with a focus on youth athletic development. The majority of participants frequently represented their state or country in their sport.

Participants undertook a battery of anthropometric measurements (body mass, stature, sitting height) on two separate occasions, separated by 7 days. Measures were obtained on the same weekday, and at the same time of day to attenuate biological sources of error (i.e. body mass fluctuations, spinal shrinkage). On each occasion, sitting height was assessed as the distance from the vertex to the base sitting surface, using three different protocols. A sitting height stadiometer (SHstad; Harpenden Sitting Table, Holtain, UK) was used as the criterion measure, a 40 cm anthropometric box (SHbox), and a gymnasium floor (SHfloor) as surrogate platforms for sitting height assessments (see figure 1). The order in which the battery was delivered was standardized between repeated observations, with all measurements performed by the same investigator (TM) who had extensive training and experience (TEM [cm]: stature=0.32; SHstad=0.33; SHbox=0.46; SHfloor=0.50). Participants wore the same training attire for repeated observations (shorts, shirt, socks) and removed footwear for all measures.

Body mass (WB-110, Tanita Corporation, Japan) was recorded with electronic scales to the nearest 0.1kg, and stature was recorded to the nearest 0.1 cm using a portable stadiometer (WS-HRP, Wedderburn, NSW, Australia). For SHstad, a stadiometer is mounted on a custom-built table with feet unsupported to facilitate a 'short-sitting' posture whereby the anterior and posterior superior iliac spines are level with minimal anterior pelvic tilt (pane A, Figure 1). The SHbox method also adopted the short-sitting position, on an anthropometric box (40 cm x 50 cm x 30 cm) with feet supported on the floor (pane B, Figure 1). The SHbox technique is widely used in both research studies (3,7) and applied practice, with frequent anecdotal reports that chairs or plinths are used as surrogate platforms. Finally, sitting height was also measured in the 'long sitting' position (pane C, Figure 1) on the gymnasium floor (SHfloor). This technique was examined considering its simple implementation in youth sport (8) and presented a potential uniform approach that can be used broadly across talent development systems to enable benchmarking. The portable stadiometer was placed on each platform for the SHbox and SHfloor techniques. For all stature methods, the head was positioned in the Frankfurt plane to perform the stretch-stature method. All measures were recorded in duplicate with a mean value used; however, where the difference between measures was >0.4cm or >0.4kg, a third measure was recorded, and the median value assigned.

Anthropometric data and chronological age on the date of assessment were inserted into three available algorithms to estimate APHV. The original male and female equations developed by Mirwald (4), and those subsequently modified to mitigate for potential over-fitting (6) and the non-linear na-

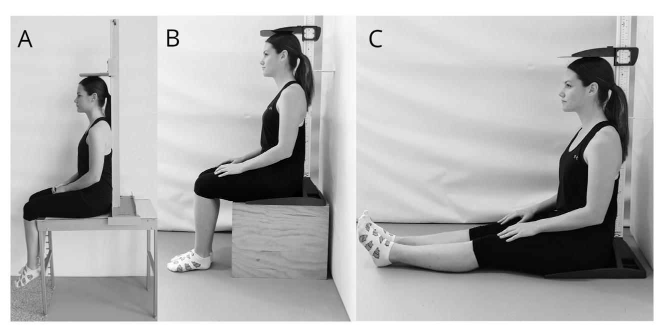

Fig. 1. Sitting height protocols assessed: A) sitting height stadiometer (SHstad); B) 40 cm anthropometric box (SHbox); long-sitting position on a gymnasium floor (SHfloor).

Table 1 Reliability Statistics for Male and Female Participants. Mean ± SD, (90% CI)

	Male					Female				
	Week 1	Week 2	Typical Error of Estimate		ICC	Week 1	Week 2	Typical Error of Estimate		ICC
			Raw Units	%CV				Raw Units	%CV	
Stature (cm)	162.1±9.2	162.1±9.2	0.32 (0.27-0.40)	0.2 (0.2-0.2)	1.00 (1.00-1.00)	163.3±8.0	163.3±8.1	0.32 (0.28-0.38)	0.2 (0.2-0.2)	1.00 (1.00-1.00)
Weight (kg)	52±9.7	52.1±9.6	0.34 (0.28-0.42)	0.6 (0.5-0.8)	1.00 (1.00-1.00)	61±14.8	61.2±14.8	0.45 (0.39-0.54)	0.7 (0.6-0.9)	1.00 (1.00-1.00)
SH_{stad} (cm)	84.4±5.7	84.4±5.6	0.29 (0.24-3.6)	0.3 (0.3-0.4)	1.00 (1.00-1.00)	86.5±4.3	86.5±4.3	0.38 (0.33-0.45)	0.4 (0.4-0.5)	0.99 (0.99-1.00)
SH_{box} (cm)	84.1±5.7	84.1±5.7	0.35 (0.3-0.44)	0.4 (0.4-0.5)	1.00 (0.99-1.00)	86.3±4.2	86.3±4.3	0.57 (0.49-0.68)	0.7 (0.6-0.8)	0.98 (0.97-0.99)
SH_{floor} (cm)	81±5.9	81.2±5.7	0.56 (0.46-0.69)	0.7 (0.6-0.9)	0.99 (0.99-1.00)	84±4.2	83.9±4.1	0.44 (0.38-0.53)	0.5 (0.5-0.6)	0.99 (0.98-0.99)
Mirwald APHV SH_{stad}	14.1±0.7	14.1±0.7	0.04 (0.03-0.05)	0.3 (0.2-0.3)	1.00 (1.00-1.00)	12.2±0.7	12.2±0.7	0.02 (0.02-0.03)	0.2 (0.2-0.2)	1.00 (1.00-1.00)
Mirwald APHV SH_{box}	14.1±0.7	14.1±0.7	0.04 (0.04-0.05)	0.3 (0.3-0.4)	1.00 (0.99-1.00)	12.2±0.7	12.2±0.7	0.03 (0.03-0.04)	0.2 (0.2-0.3)	1.00 (1.00-1.00)
Mirwald APHV SH_{floor}	14.5±0.7	14.5±0.7	0.07 (0.06-0.09)	0.5 (0.4-0.6)	0.99 (0.98-0.99)	12.3±0.8	12.3±0.8	0.03 (0.02-0.03)	0.2 (0.2-0.2)	1.00 (1.00-1.00)
Moore APHV SH_{stad}	13.8±0.5	13.9±0.5	0.03 (0.02-0.04)	0.2 (0.2-0.3)	1.00 (0.99-1.00)	*12.1±0.5	*12.1±0.5	*0.02 (0.02-0.02)	*2.5 (2.2-3.0)	*1.00 (1.00-1.00)
Moore APHV SH_{box}	13.9±0.5	13.9±0.5	0.03 (0.03-0.04)	0.3 (0.2-0.3)	1.00 (0.99-1.00)	*	*	*	*	*
Moore APHV SH_{floor}	14.2±0.5	14.2±0.5	0.06 (0.05-0.07)	0.4 (0.3-0.5)	0.99 (0.98-0.99)	*	*	*	*	*
Fransen APHV SH_{stad}	13.9±0.7	14±0.7	0.04 (0.03-0.05)	0.3 (0.2-0.3)	1.00 (0.99-1.00)	-	-	-	-	-
Fransen APHV SH_{box}	14±0.7	14±0.7	0.05 (0.04-0.06)	0.3 (0.3-0.4)	1.00 (0.99-1.00)	-	-	-	-	-
Fransen APHV SH_{floor}	14.5±0.7	14.4±0.7	0.10 (0.08-0.12)	0.7 (0.6-0.9)	0.98 (0.97-0.99)	-	-	-	-	-

*Moore Female Equation does not utilize sitting height. - Fransen Equation is as yet, valid only for male adolescents.
ICC = Intraclass Correlation; APHV = Age at Peak Height Velocity; SH_{stad} = sitting height determined via sitting height stadiometer; SH_{box} = sitting height determined via 40cm anthropometric box; SH_{floor} = sitting height determined via sitting on floor.

Table 2 Validity Statistics for Male and Female Participants, (90% CI)

	Male				Female			
	Typical Error of Estimate		Pearson Correlation	Bland - Altman	Typical Error of Estimate		Pearson Correlation	Bland - Altman
	Raw Units	%			Raw Units	%		
Sitting Height (cm)								
SH_{stad} vs SH_{box}	0.56 (0.47-0.70)	0.7 (0.6-0.8)	1.00 (0.99-1.00)	1.09	0.64 (0.55-0.77)	0.7 (0.6-0.9)	0.99 (0.98-0.99)	1.25
SH_{stad} vs SH_{floor}	0.83 (0.70-1.04)	1.0 (0.8-1.2)	0.99 (0.98-0.99)	1.7	0.89 (0.77-1.07)	1.0 (0.9-1.2)	0.98 (0.97-0.99)	1.74
APHV (years)								
Mirwald SH_{stad} vs SH_{box}	0.07 (0.06-0.09)	0.5 (0.4-0.6)	1.00 (0.99-1.00)	0.13	0.03 (0.02-0.03)	0.2 (0.2-0.3)	1.00 (1.00-1.00)	0.06
Mirwald SH_{stad} vs SH_{floor}	0.11 (0.09-0.13)	0.8 (0.6-0.9)	0.99 (0.98-0.99)	0.21	0.05 (0.04-0.06)	0.4 (0.3-0.5)	1.00 (1.00-1.00)	0.1
Moore SH_{stad} vs SH_{box}	0.05 (0.05-0.07)	0.4 (0.3-0.5)	0.99 (0.99-1.00)	0.11	*	*	*	*
Moore SH_{stad} vs SH_{floor}	0.08 (0.07-0.10)	0.6 (0.5-0.8)	0.99 (0.98-0.99)	0.17	*	*	*	*
Fransen SH_{stad} vs SH_{box}	0.07 (0.06-0.09)	0.5 (0.5-0.7)	0.99 (0.99-1.00)	0.14	-	-	-	-
Fransen SH_{stad} vs SH_{floor}	0.16 (0.13-0.20)	1.1 (1.0-1.4)	0.97 (0.96-0.99)	0.31	-	-	-	-

*Moore Female Equation does not utilize sitting height. - Fransen Equation is currently, valid only for male adolescents. ICC = Intraclass Correlation; APHV = Age at Peak Height Velocity; SH_{stad} = sitting height determined via sitting height stadiometer; SH_{box} = sitting height determined via 40cm anthropometric box; SH_{floor} = sitting height determined via sitting on floor.

ture of adolescent growth (5) were used considering some of the errors identified with the original maturity offset predictions (9,10). Female APHV was only determined via the Mirwald method (4), since Fransen maturity ratio (5) has not been validated in female adolescents, and the Moore algorithm (6) for females does not include sitting height as a coefficient in the model.

Statistical analysis. Sitting height methods and estimated APHV obtained from the three prediction algorithms were inserted into custom spreadsheets to assess reliability and validity. For both measurement properties, typical error of the estimate was expressed in both raw units (TEE), and as a percentage (coefficient of variation; CV) derived from log-transformed data (11). Agreement was determined via intra-class correlation coefficients for reliability and via both Pearson correlations and Bland-Altman limits of agreement for validity. Between method differences were examined using linear-mixed models, clustering for the repeated measures for the data collected in week 1 and 2. Effect statistics and their associated p-values were inserted into a customized spreadsheet to determine magnitude-based inferences (12).

Results

Applying the gender-specific original prediction equations of Mirwald (4), and using the criterion measure for sitting height, the estimated maturity offset of males and females in this study was +0.1 (±1.2) and +2.0 (±1.0) years, respectively. Reliability and validity statistics are presented in Tables 1 and 2, respectively.

All measures of sitting height, and their respective estimations of APHV showed strong week-to-week reliability for both genders (CV $\leq$ 2.5%; ICC: $\geq$ 0.98). In boys, SHfloor demonstrated subtly lower reliability (TEE: 0.56 cm; CV: 0.7 %) versus SHstad (TEE: 0.29 cm; CV: 0.3 %) and SHbox (TEE: 0.35 cm; CV: 0.4 %), which translated in to lower week-to-week agreement for each APHV estimation (TEE: SHfloor = 3.1-5.2; SHbox = 1.6-2.6; SHstad: 1.6-2.1 weeks). Girls had slightly weaker reliability for SHbox (TEE: SHbox = 0.57; SHfloor = 0.44; SHstad: 0.38 cm), but this did not translate into differences in estimated APHV.

Agreement between proxy (SHbox, SHfloor) and criterion measures of sitting height (SHstad) were good, irrespective of gender ($r \geq 0.97$). For both genders, measures of sitting height determined via SHbox demonstrated most likely trivial differences compared with SHstad (mean difference = 0.23-0.30 cm; see figure 2). Whereas SHfloor demonstrated very likely small decreases versus both SHstad and SHbox ($p<0.0001$; mean difference = 2.37-3.32 cm).

Comparing the APHV estimations using each of the 3 equations for males showed most likely trivial differences between SHstad and SHbox ($p=0.0503$; mean difference =0.037 years), but SHfloor resulted in a delayed APHV estimation by approximately 5 months (likely-very-likely small effects; $p<0.0001$; see figure 3). Comparisons between APHV for females using the Mirwald equation showed unclear or trivial differences between sitting height measures.

Discussion

This study primarily aimed to compare the measurement accuracy of commonly implemented sitting height techniques used to predict APHV. All three sitting positions demonstrated strong reliability irrespective of gender (ICC: $\geq$ 0.98; CV $\leq$ 0.7%), which translated into APHV estimations (ICC: $\geq$ 0.98; CV $\leq$ 0.7%). With respect to validity, both surrogate measures of sitting height showed strong agreement (SHbox: TEE $\leq$ 0.64 cm; $r \geq 0.99$; SHfloor: $\leq$ 0.89cm; $r \geq 0.98$). However, in males, SHfloor under-estimated sitting height, which resulted in a delayed prediction APHV by approximately 5 months.

The strong reliability results found here support previous work using both the SHbox (13) and SHstad (14) in conjunction with the Mirwald algorithm (4) to estimate APHV. Considering the strong agreement in both sitting height and APHV between SHbox and the criterion (SHstad), our data suggest SHbox to be a suitable surrogate measure and more practical application versus SHstad in youth sport programs. Alternatively, the lower absolute heights and test-retest reliability recorded with SHfloor are in accordance with previous work (8) and resulted in a ~5-month over-estimation in males APHV, consistent in each predictive algorithm used. That the same measurement error was not observed in females is likely due to the comparatively lower weighting of sitting height in female APHV estimation algorithms (4), and explains its omission from recent modifications (6).

Despite similar chronological ages, the male participants in this study were much closer to APHV than females, potentially limiting the generalization of the findings as APHV estimation accuracy is poorer further from true APHV. Our sample was also ethnically diverse, yet APHV prediction algorithms were originally developed from Caucasian adolescents, and the influence of ethnicity is presently unknown. Finally, the im-

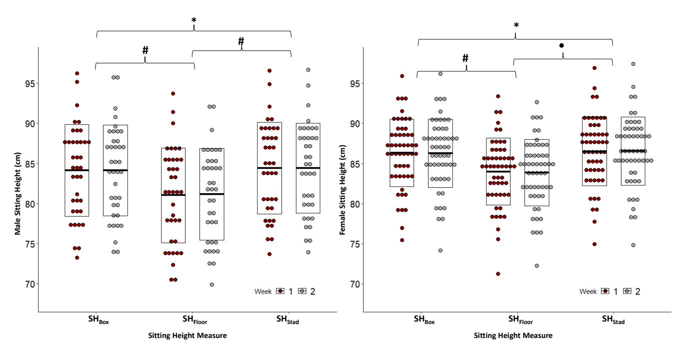

Fig. 2. Sitting height measurements attained using the three protocols, for males (left) and females (right). Thick horizontal bars represent the mean, upper and lower crossbars depict ± one standard deviation, and dots signify individual participant sitting height. * = most likely trivial difference, ● = most likely small difference, # = very likely small difference

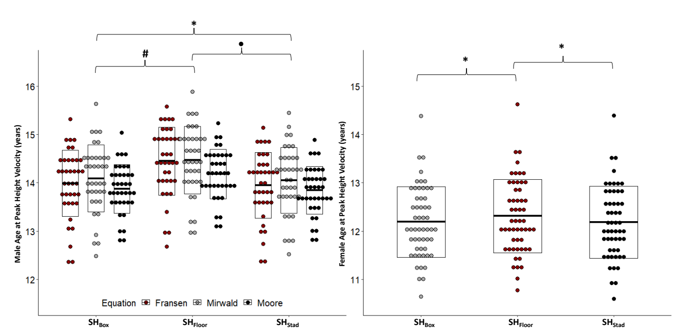

Fig. 3. Age at Peak Height Velocity (APHV) attained using the three sitting height protocols, colour coded by the estimating equation used. Males displayed on the left and females on the right. Female APHV estimated using only Mirwald equation. Thick horizontal bars represent the mean, upper and lower crossbars depict ± one standard deviation, and dots signify individual participant sitting height. * = most likely trivial difference, ● = most likely small difference, # = very likely small difference.

pact of sitting height techniques upon APHV prediction for females was only currently available via the Mirwald (4) equation. Further research may be necessary to examine these limiting factors.

In summary, all three sitting height measures showed strong measurement accuracy, but using an anthropometric box was a more appropriate surrogate measure to the use of a sitting height table and may have practical validity in talent development systems due to its limited cost and portability. Those adopting estimations of somatic maturity from anthropometric measurements are cautioned in comparing APHV between different sitting height protocols, particularly in males, and should consider the overestimation of APHV using the long-sitting position.

Practical Applications

- Each of the sitting height protocols assessed in this study showed strong intra-rater agreement, and were near perfectly correlated to the criterion measure (sitting height stadiometer) in both males and females.
- However, adopting a long-sitting position in boys reduced sitting height, leading to a ∼5 month delay in estimated age at peak height velocity.
- Where a sitting height stadiometer is not available, we would recommend the short sitting position, ideally on an anthropometric box and ensuring appropriate measurement posture.
- Practitioners and coaches should pay strict attention to anthropometric measurement principles, and in particular ensure consistent sitting height protocols are used to track growth and estimate maturation status.

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