Does Controlling for Biological Maturity Improve Physical Activity Tracking?

MARTA C. ERLANDSON[1], LAUREN B. SHERAR[1], AMBER D. MOSEWICH[2], KENT C. KOWALSKI[1], DONALD A. BAILEY[1,3], and ADAM D. G. BAXTER-JONES[1]

[1]*College of Kinesiology, University of Saskatchewan, Saskatoon, Saskatchewan, CANADA;* [2]*School of Human Kinetics, University of British Columbia, Vancouver, British Columbia, CANADA; and* [3]*School of Human Movement, University of Queensland, Brisbane, AUSTRALIA*

ABSTRACT

ERLANDSON, M. C., L. B. SHERAR, A. D. MOSEWICH, K. C. KOWALSKI, D. A. BAILEY, and A. D. G. BAXTER-JONES. Does Controlling for Biological Maturity Improve Physical Activity Tracking? *Med. Sci. Sports Exerc.*, Vol. 43, No. 5, pp. 800–807, 2011. Tracking of physical activity through childhood and adolescence tends to be low. Variation in the timing of biological maturation within youth of the same chronological age (CA) might affect participation in physical activity and may partially explain the low tracking. **Purpose**: To examine the stability of physical activity over time from childhood to late adolescence when aligned on CA and biological age (BA). **Methods**: A total of 91 males and 96 females aged 8–15 yr from the Saskatchewan Pediatric Bone Mineral Accrual Study (PBMAS) were assessed annually for 8 yr. BA was calculated as years from age at peak height velocity. Physical activity was assessed using the Physical Activity Questionnaire for Children/Adolescents. Tracking was analyzed using intraclass correlations for both CA and BA (2-yr groupings). To be included in the analysis, an individual required a measure at both time points within an interval; however, not all individuals were present at all tracking intervals. **Results**: Physical activity tracking by CA 2-yr intervals were, in general, moderate in males (r = 0.42–0.59) and females (r = 0.43–0.44). However, the 9- to 11-yr CA interval was low and nonsignificant (r = 0.23–0.30). Likewise, tracking of physical activity by BA 2-yr intervals was moderate to high in males (r = 0.44–0.60) and females (r = 0.39–0.62). **Conclusions**: Accounting for differences in the timing of biological maturity had little effect on tracking physical activity. However, point estimates for tracking are higher in early adolescence in males and to a greater extent in females when aligned by BA versus CA. This suggests that maturity may be more important in physical activity participation in females than males. **Key Words:** LONGITUDINAL, CHILDHOOD, ADOLESCENT, PUBERTY

Physical activity levels have generally been reported to decline from childhood through adolescence and into adulthood (19,39,43). Physical activity is important as it is a critical component of a healthy lifestyle, and in adults, it has been found to be related to a lower risk of developing serious illnesses such as cardiovascular disease (4,44), type 2 diabetes (4), and some cancers (6,12,23). Physical activity is thus promoted as a preventative measure for illnesses in both adults and children. Children and adolescents have been targeted based on the premise that increased physical activity during childhood and adolescence will not only bring about immediate health benefits but also track into adulthood and thus be indirectly related to later health (41). Tracking refers to the tendency of an individual variable to maintain its position or rank within a specific group over time (24) and is generally expressed by calculating the correlation between repeated measurements of the same attribute (e.g., physical activity) in the same individual.

Information on how physical activity tracks is important for promotion and implementation of activity interventions. If tracking of physical activity is high from childhood to adulthood, then implementing early interventions is crucial for population level change; however, if tracking is low, suggesting that being an inactive child does not predicate being an inactive adult, then intervention strategies later in life may be more effective. Several studies have assessed tracking of physical activity, and on average, results show low to moderate stability through childhood and adolescence (1,16,17,22,27,28,41,43) and into young adulthood (8,15,24, 26,36,40). This low level of tracking indicates that there is considerable within-individual variability in physical activity participation during adolescence. There is good reason to believe that pubertal development, otherwise termed *biological maturation*, might affect adolescent participation in physical activity participation and may partially explain the low tracking through adolescence (5).

Adolescence hosts momentous physiological, psychological, social, and behavioral changes. It is likely that the change in physiology (e.g., development of secondary sex

Address for correspondence: Adam Baxter-Jones, College of Kinesiology, University of Saskatchewan, 87 Campus Dr., Saskatoon, Saskatchewan, Canada S7N 5B2; E-mail: baxter.jones@usask.ca.
Submitted for publication June 2010.
Accepted for publication September 2010.

0195-9131/11/4305-0800/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0b013e3181ffee8a

characteristics, growth spurt in height, etc.) during adolescence, and the social and psychological implications of these changes, affects participation in physical activity. For example, the appearance of secondary sex characteristics, in particular breast development, may contribute to feelings of self-consciousness and perceptions of discomfort associated with participation in physical activity (34). If these changes were to occur at the same time (i.e., age) in every individual, biological maturity would likely not affect the tracking of physical activity; however, this is not the case. The onset of puberty can vary by as much as 4–5 yr among normal healthy boys and girls (35). Thus, the different degrees of biological maturity attained by children of the same chronological age (CA) will likely present variable influences on participation in physical activity. There is evidence to suggest that sex differences in biological maturation contribute to physical activity during late childhood and adolescence (11,33,38). Furthermore, Riddoch et al. (29) showed that the development of secondary sex characteristics was inversely related to physical activity among 2933 11-yr-old girls, suggesting that biological maturity also plays a role in physical activity within a sex with late maturing girls participating in more activity than early maturing girls.

With regard to the role of biological maturity in tracking of physical activity, Baggett et al. (2) found low to moderate tracking coefficients between 11 and 14 yr in girls. The authors suggested that differences in the tempo and timing of sexual maturation might have reduced the tracking during this period. However, with no measure of biological maturity, they were unable to support or refute this suggestion. In fact, to our knowledge, the effect of variation in pubertal development (or biological maturity) on the tracking of physical activity has yet to be investigated.

In summary, individuals experience dramatic physiological changes during adolescence, which likely influence participation in physical activity. Because of the considerable variation in the timing of these changes, when physical activity is aligned to CA, the relative order of individuals within a group will likely change. This change could lead to low tracking. On the basis of this conjecture, when physical activity is aligned to biological age (BA; such as years from the adolescent growth spurt in height), tracking will improve. Thus, the purpose of this study was to examine tracking of physical activity over time from childhood to late adolescence when aligned on CA and BA.

We hypothesized that tracking coefficients would be low to moderate when aligned by a CA scale but would yield higher point estimates for tracking when data were aligned by a BA scale.

METHODS

Participants and procedure. Participants were part of the University of Saskatchewan's Pediatric Bone Mineral Accrual Study (PBMAS; 1991–1998), which has been described in detail elsewhere (38). In brief, the study used a mixed longitudinal design incorporating eight age cohorts. The cohorts were aged between 8 and 15 yr at study entry. During 8 yr of serial data collection, the composition of these clusters remained the same; however, the individuals in each tracking group differed slightly (Table 1) because of differing ages of entry into the study and missed measurements. Between 1991 and 1993, written informed consent was obtained from 251 parents and their children. Of the 94% of participants whose race were known, 95% were Caucasian. By 1998, 197 individuals had been assessed on two or more occasions. To be included in the present study, each participant required complete measurements (CA, BA, and physical activity) on at least two measurement occasions separated by 2 yr (e.g., 9 and 11 yr). Therefore, 187 individuals were included in the analysis, 91 males and 96 females; however, it should be noted that not all individuals had measures at all time points. Thirty females and 35 males were present at every time point for both chronological and biological 2-yr age groupings. Data from an 8-yr period (9–17 yr) was used in the present analysis to

BASIC SCIENCES

TABLE 1. Subject characteristics by sex and CA tracking groups.

Tracking Groups (yr)	CA Group	*n*	Age (yr)	Height (cm)	Weight (kg)	BMI (kg·m^{-2})	PA	Years from APHV
Boys								
9–11	9	15	9.2 (0.3)	137.9 (4.8)	32.6 (4.9)	17.2 (2.6)	2.95 (0.83)	−4.03 (0.93)*
	11	15	11.2 (0.4)	148.0 (6.4)	40.2 (6.6)	18.4 (3.2)	3.44 (0.59)	−2.18 (1.01)*
11–13	11	47	11.1 (0.4)	148.2 (6.7)	40.1 (7.5)	18.2 (2.9)	3.30 (0.59)*	−2.34 (1.10)*
	13	47	13.1 (0.3)	161.1 (8.3)	51.3 (9.8)	19.7 (3.4)	3.07 (0.60)*	−0.34 (0.15)*
13–15	13	54	13.0 (0.3)	161.5 (8.1)	51.4 (9.5)	19.6 (3.0)	3.20 (0.60)*	−0.33 (0.13)*
	15	54	15.0 (0.3)	174.5 (7.4)	64.4 (10.6)	21.1 (3.1)	2.86 (0.59)	1.70 (1.03)*
15–17	15	50	15.0 (0.3)	174.4 (7.6)*	64.2 (10.3)	21.1 (3.0)	2.99 (0.59)*	1.63 (0.98)*
	17	50	17.0 (0.3)	178.5 (7.2)*	72.9 (11.4)*	22.9 (3.5)	2.45 (0.68)*	3.62 (0.99)*
Girls								
9–11	9	25	9.1 (0.2)	137.8 (9.1)	33.4 (9.1)	17.3 (2.9)	3.11 (0.65)	−2.32 (1.04)
	11	25	11.1 (0.3)	150.6 (9.9)	43.5 (11.6)	18.9 (3.8)	3.09 (0.57)	−0.33 (1.01)
11–13	11	55	11.1 (0.3)	148.6 (8.8)	39.5 (9.9)	17.7 (3.1)	2.96 (0.57)	−0.62 (0.14)
	13	55	13.0 (0.3)	160.9 (7.8)	51.3 (11.5)	19.6 (3.3)	2.74 (0.63)	1.35 (0.14)
13–15	13	68	13.0 (0.3)	159.8 (6.8)	50.8 (10.6)	19.8 (3.3)	2.87 (0.63)	1.24 (0.09)
	15	68	15.0 (0.2)	164.4 (5.9)	57.8 (10.6)	21.3 (3.6)	2.54 (0.57)	3.22 (0.79)
15–17	15	48	15.0 (0.4)	164.5 (5.8)	59.4 (11.4)	21.9 (3.9)	2.70 (0.57)	2.96 (0.79)
	17	48	17.0 (0.3)	165.6 (5.9)	63.4 (12.7)	23.1 (4.4)	2.24 (0.68)	4.88 (0.68)

* Significant difference between sexes, $P < 0.05$.
PA, physical activity; APHV, age at peak height velocity; BMI, body mass index; CA, chronological age.

assess the effect of tracking during the circum-pubertal years. The study received approval from the University and Hospital Advisory Committee on Ethics in Human Experimentation. Informed consent was provided in writing by all guardians, and assent was provided by all participants.

CA. CA (yr) was calculated by subtracting the decimal year of an individual's date of birth from the decimal year of the measurement occasion. One-year intervals were used to construct CA groups. Age groups were set up such that the 9-yr age group included observations between 8.50 and 9.49 yr.

Anthropometry. Anthropometric measurements, including height, sitting height, and body mass, were taken at 6-month intervals by International Society for the Advancement of Kinanthropometry–certified personnel, according to the International Society for the Advancement of Kinanthropometry standards for anthropometric measurement (37). During measurements, participants wore T-shirts and loose-fitting shorts, with shoes and jewelry removed. Height was measured as stretch stature to the nearest 0.1 cm using a wall stadiometer. Body mass was measured on a calibrated electronic scale and recorded to the nearest 0.1 kg. Body mass index (BMI) was calculated as weight (kg) per squared height (m^2). After measurements were obtained, each participant's results were compared with previously recorded results to verify an increase or plateau in values as evidence of confidence in the measurements.

BA. Age at peak height velocity (APHV) reflects the maximum growth in stature during a 1-yr time interval in adolescence and also acts as an indicator of biological maturation (38). Using a cubic spline procedure, a growth curve was fitted to each individual's annual height velocity data (GraphPad Prism version 3.00 for Windows; GraphPad Software, San Diego, CA) and APHV was established. A cubic spline interpolates polynomials from information of neighboring points with the goal of obtaining global smoothness. The cubic spline directs the curve through each data point. This approach has the advantage of enhanced flexibility and the ability to preserve the accuracy of the data because averaging group data does not modify each participant's APHV.

BA was calculated by subtracting APHV from CA at the time of measurement. BA groups (categories) were then constructed in the same manner as the CA groups, such that measurements between −2.49 and −1.50 yr from APHV were included in the −2 yr from APHV group. Physical activity measurements were considered in terms of years before and after APHV.

Physical activity. The Physical Activity Questionnaire for Children (PAQ-C) (10,20) and Physical Activity Questionnaire for Adolescents (PAQ-A) (21) were developed for the PBMAS to assess general levels of physical activity during the school year for students beyond grade 3. The PAQ-C was administered to children in elementary school (grades 3–8) and PAQ-A was administered once they reached high school (grades 9–12). The two questionnaires are identical with the exception of one question in the PAQ-C, which enquires about activity during recess, which is not present in the PAQ-A (as high school students do not have recess). They are self-administered 7-d recall questionnaires, which ask students to recall their physical activity for the last 7 d. The PAQ-C and PAQ-A were completed in a classroom setting in approximately 10–15 min. There is reliability and validity evidence supporting use of the PAQ-C and PAQ-A with children and adolescents (10,20,21).

The PAQ-C and PAQ-A measures were administered a minimum of three times per year for the first 3 yr of the study and two times per each subsequent year during childhood and adolescence. Scores were averaged during each year period to create a single score for CA and BA. The PAQ-C is a reliable measure to assess physical activity in both younger (9–12 yr) and older (13–15 yr) children. The test–retest reliability was $r = 0.75$ for males and $r = 0.82$ for females (10). The generalizability coefficients exceeded 0.80 for either the average of two or three measurement occasions within the same year (10). The PAQ-A has also

TABLE 2. Subject characteristics by sex and BA tracking groups.

Tracking Groups	BA Group	*n*	Age (yr)	Height (cm)	Weight (kg)	BMI (kg·m^{-2})	PA	Years from APHV
Boys								
−4 to −2	−4	25	9.9 (0.9)	140.4 (5.6)	33.8 (6.2)	17.1 (2.9)	3.21 (0.79)	−3.92 (0.20)
	−2	25	12.0 (1.0)	150.8 (5.4)	42.6 (3.4)	18.4 (3.4)	3.27 (0.53)	−1.86 (0.37)
−2 to 0	−2	46	11.7 (1.0)	150.6 (5.4)	41.5 (7.0)	18.3 (2.9)	3.32 (0.53)	−1.96 (0.21)
	0	46	13.6 (1.1)	164.1 (6.1)	52.9 (8.3)	19.6 (2.9)	2.94 (0.66)	0.02 (0.23)
0 to 2	0	56	13.5 (1.0)	165.4 (7.5)	53.7 (9.1)	19.6 (2.6)	3.08 (0.66)	0.03 (0.22)
	2	56	15.5 (1.0)	177.5 (7.0)	67.6 (9.9)	21.4 (2.7)	2.77 (0.57)	2.03 (0.23)
2 to 4	2	45	15.2 (1.1)	176.6 (7.1)	65.8 (10.1)	21.0 (2.6)	2.91 (0.57)	2.07 (0.45)
	4	45	17.1 (0.9)	179.3 (6.9)	73.8 (11.2)	23.0 (3.3)	2.46 (0.68)	4.00 (0.26)
Girls								
−3 to −1	−3	22	9.6 (0.6)	137.2 (7.1)	31.9 (7.1)	16.8 (2.4)	2.97 (0.60)	−2.92 (0.23)
	−1	22	11.6 (0.6)	147.9 (7.9)	41.3 (9.2)	18.7 (3.0)	2.97 (0.60)	−0.97 (0.24)
−1 to 1	−1	45	10.9 (0.8)	146.0 (7.3)	38.3 (9.0)	17.8 (3.0)	3.05 (0.60)	−0.99 (0.24)
	1	45	12.9 (0.8)	160.5 (7.1)	50.6 (10.7)	19.5 (3.2)	2.91 (0.63)	0.99 (0.25)
1 to 3	1	69	12.7 (1.0)	160.0 (6.6)	50.7 (11.1)	19.8 (3.7)	2.83 (0.63)	0.96 (0.27)
	3	69	14.7 (0.9)	166.1 (6.2)	59.0 (11.3)	21.3 (3.7)	2.56 (0.65)	2.98 (0.27)
3 to 5	3	55	14.7 (0.8)	165.0 (6.2)	59.1 (11.5)	21.6 (3.7)	2.74 (0.65)	2.91 (0.28)
	5	55	16.7 (0.8)	165.5 (5.5)	62.2 (12.0)	22.7 (4.1)	2.22 (0.65)	4.95 (0.29)

Observations that fell outside −4 to +4 for boys and −3 to +5 for girls were excluded because of small number.
PA, physical activity; APHV, age at peak height velocity; BMI, body mass index; BA, biological age.

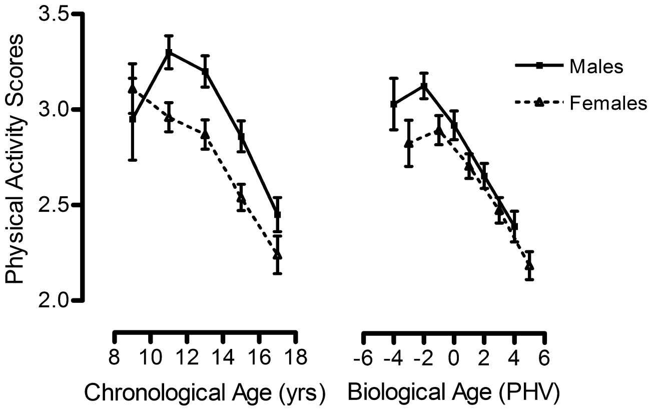

FIGURE 1—Physical activity scores by CA and BA scales.

found to be a reliable assessment physical activity with generalizability coefficients of 0.85 for the average of two scores and 0.90 for the average of three scores administered during a 1-yr period (21).

Statistical analysis. Sex differences in age, height, weight, BMI, physical activity, and year from APHV were assessed using independent-sample *t*-tests at each age. Intraclass correlation coefficients were used to assess the stability of physical activity over time. Participants were divided into 2-yr groups based on CA or BA. For inclusion in the analysis, an individual required a measure of physical activity at both time points (e.g., for inclusion in the 2-yr interval from 9 to 11 yr, a measure of physical activity was required at both 9 and 11 yr). The correlation assessed the stability of an individual's mean physical activity score between the two time points. A correlation of <0.30 was interpreted as a low correlation; 0.30 to 0.60 as a moderate correlation; and >0.60 as a moderately high correlation (24). BA and CA correlations were compared by examining if one point estimate was greater than the other. The Statistical Package for the Social Sciences (version 18.0; SPSS, Inc., Chicago, IL) was used to analyze the data. The α level of significance was set at $P < 0.05$.

RESULTS

Participants' physical characteristics and physical activity, by CA and BA category, are shown in Tables 1 and 2, respectively. As expected when aligned by either CA or BA, both males and females gained height and weight with increasing age. BMI also increased with increasing CA and BA. On the basis of Cole's International cutoff points for overweight and obesity, on average, boys and girls had a normal BMI at all CA (9). Physical activity decreased with increasing CA and BA. As expected, boys were significantly less mature than girls at each CA group (Table 1). Furthermore, boys were significantly more active than girls at each CA group (with the exception of 9 and 11 yr), but these differences disappeared when data were aligned on BA (38).

The longitudinal developmental pattern of physical activity according to both CA and BA is presented in Figure 1. Physical activity reached its peak in late childhood around 10 yr (Fig. 1A) after which physical activity levels decreased with increasing CA for both sexes until approximately 15–17 yr. When data were aligned to a BA scale (i.e., years from APHV) physical activity reached its peak approximately 1 yr before APHV (Fig. 1B) with a subsequent decrease until 3–4 yr after APHV in both sexes.

Tracking coefficients of physical activity for 2-yr intervals by CA and BA are presented in Table 3. All tracking coefficients were significant, with the exception of 9–11 yr. Moderate to high tracking of physical activity (0.39–0.62) was observed when participants were aligned by CA and BA. Aligning participants by biological maturation did not improve the point estimate of the tracking coefficient consistently over adolescence. However, the point estimates did improve in early adolescence when aligned by BA in males

TABLE 3. Intraclass correlation coefficients for 2-yr intervals by CA and BA.

	n	X_A[a]	X_B[b]	r	95% CI	P
CA intervals for males						
9–11	15	2.94 (0.83)	3.33 (0.59)	0.30	−0.22 to 0.69	>0.05
11–13	47	3.33 (0.59)	3.20 (0.60)	0.59	0.37 to 0.75	<0.05*
13–15	54	3.20 (0.60)	2.91 (0.59)	0.57	0.36 to 0.72	<0.05*
15–17	50	2.91 (0.59)	2.47 (0.63)	0.42	0.16 to 0.62	<0.05*
CA intervals for females						
9–11	25	3.05 (0.65)	2.98 (0.57)	0.23	−0.17 to 0.56	>0.05
11–13	55	2.98 (0.57)	2.80 (0.63)	0.44	0.20 to 0.63	<0.05*
13–15	68	2.80 (0.63)	2.59 (0.57)	0.43	0.21 to 0.60	<0.05*
15–17	48	2.59 (0.57)	2.24 (0.68)	0.44	0.18 to 0.64	<0.05*
BA intervals for males						
−4 to −2	25	3.19 (0.79)	3.31 (0.53)	0.46	0.09 to 0.72	<0.05*
−2 to 0	46	3.30 (0.56)	3.09 (0.66)	0.48	0.23 to 0.67	<0.05*
0 to 2	56	3.09 (0.66)	2.86 (0.62)	0.60	0.41 to 0.75	<0.05*
2 to 4	45	2.86 (0.62)	2.45 (0.62)	0.44	0.17 to 0.65	<0.05*
BA intervals for females						
−3 to −1	22	2.97 (0.60)	3.05 (0.60)	0.62	0.28 to 0.82	<0.05*
−1 to 1	45	3.05 (0.60)	2.81 (0.63)	0.48	0.22 to 0.68	<0.05*
1 to 3	69	2.80 (0.63)	2.62 (0.65)	0.48	0.27 to 0.64	<0.05*
3 to 5	55	2.62 (0.65)	2.24 (0.65)	0.39	0.14 to 0.59	<0.05*

[a] First mean physical activity level in the interval (the smaller of the two numbers).
[b] Second mean physical activity level in the interval (the larger of the two numbers).
* The correlation is significant.

BASIC SCIENCES

(0.30 ($P > 0.05$) vs 0.46 ($P < 0.05$)) and, to a greater extent, in females (0.23 ($P > 0.05$) vs 0.62 ($P < 0.05$)).

DISCUSSION

The purpose of this study was to examine the stability of physical activity over time from childhood to late adolescence in boys and girls when aligned on CA and BA to see if controlling for differences in biological maturity improves the tracking of physical activity. As previously shown in this sample (38), physical activity decreased with increasing CA from late childhood into adolescence, with girls being less active than boys when aligned by CA. Physical activity was found to peak in late childhood generally around 10 yr for both males and females followed by a decline during adolescence. This decrease in physical activity was also evident when analyzed by BA, with physical activity peaking before APHV and then steadily declining into late adolescence. However, the decrease in physical activity reached a subsequent plateau at approximately 15–17 yr or 3–4 yr after APHV. Furthermore, the sex difference in PA disappeared when aligned by BA. Within this group of individuals, an average decline in PA by CA and BA has been observed (38); however, this gives no information as to individuals' PA levels in relation to their peers (i.e., are the most active in early adolescence still the most active in late adolescence, regardless of the decline in PA over this period?). Thus, we used intraclass correlations to examine the ranking of participants in terms of PA levels when aligned by CA and BA.

Previous research has demonstrated low to moderate tracking of physical activity from childhood to adolescence into young adulthood (7,8,16,17,24,26,27,36,40,43), indicating considerable within-individual variability and that BA may be more closely related to physical activity than CA (13,38). Thus, based on these findings, we hypothesized that physical activity would track better when aligned by BA than CA. Contrary to our hypothesis, when data were aligned to BA, it did not yield tighter, less variable point estimates for tracking than data aligned to CA. In fact, there was no consistent difference in the 2-yr tracking estimates when aligned on BA and CA scales. With the exception of two tracking groups (−3 to −1 yr and 15–17 yr), boys showed slightly higher point estimates than girls when aligned on both CA and BA. In boys, the tracking of physical activity seemed to improve slightly with increasing age and maturity, with the highest coefficients occurring between 13 and 15 yr and between 0 and 2 yr after APHV.

Partial support for the hypotheses was found during early adolescence. Point estimates for tracking were very similar when aligned by CA and BA with the exception of early adolescence when girls' point estimates improved considerably when aligned by BA ($r = 0.62$) than CA ($r = 0.23$) and boys' tracking estimates improved, albeit more moderately ($r = 0.46$ vs $r = 0.30$). So, although aligning physical activity data by BA did not consistently improve the tracking point estimates as hypothesized, it does seem to improve tracking of physical activity during early adolescence, especially in females. However, it should be noted that the tracking coefficients between 9 and 11 yr were not significant, and thus, our confidence in these two coefficients is reduced.

The greater point estimates for tracking of physical activity during early adolescence in females could be a reflection of the early maturing girls dropping out of physical activity when they experience dramatic physical changes, such as an increase in fat deposition, breast development, and widening of the hips (35). These physical changes can influence a girl's performance and also willingness to be physically active (32). A reason why we do not observe the same magnitude of improvement in males' point estimates could be because the physical changes occurring during adolescence in males are less detrimental to physical performance and, therefore, physical activity participation. The physical changes that males experience such as gains in height, weight, weight for height, and lean mass, result in a physique better suited for success in many forms of physical activity, particularly those that emphasize speed, power, and strength (14,30). Although, as shown in this study and in numerous others (18,39,42), males display a decrease in physical activity during adolescence, it may be that biological maturity plays less of a role in the adolescent decline in physical activity in males.

In the present study, the 2-yr PA tracking coefficients were, in general, moderate to high when aligned on either BA or CA. This is in contrast to the majority of previous literature, which has found low to moderate tracking of PA during adolescence (1,16,17,22,25,27,28,43). Malina (24), in a comprehensive review of tracking literature, found that the majority (81%) of interage correlations fell between 0.10 and 0.49. However, caution must be taken when comparing results. In the present study, intraclass correlations were considered if they had $P < 0.05$, which indicates that we can be confident in the r value (tracking coefficient), but this was not the case in all studies reviewed by Malina (24). In fact, the two nonsignificant tracking coefficients observed between 9 and 11 yr were low to moderate ($r = 0.23$ for females and 0.30 for males). The inclusion of nonsignificant interage correlations in past work could explain some of the discrepancies between the current findings and previous research.

Another possible explanation for the higher tracking coefficients may be related to the manner in which the physical activity data were collected. The PAQ-C and PAQ-A measures were administered a minimum of three times per year for the first 3 yr of the study and two times per each subsequent year during adolescence. The physical activity score may be stronger because scores were averaged during each year period to create a single score for each CA and BA. The use of multiple sampling may have created a more accurate picture of physical activity participation. The PAQ-C and PAQ-A are self-report questionnaires; therefore, the data may be influenced by the ability of a child, especially at younger ages, to accurately recall activity levels. However, both questionnaires were structured by segmenting the day (before school, at lunch, etc.) and separating weekday and weekend activities, which has been found to enhance memory recall in children (3). In addition, research has found little difference in reliability between younger (aged 9–12 yr) and older (aged 13–15 yr) children (10).

Anderssen et al. (1) proposed explanations as to why tracking of physical activity during adolescence may be stronger in some samples than others. They suggested that the tracking of physical activity may be related to stable psychological characteristics of the individual (e.g., a psychological readiness for physical activity and a propensity for sports involvement). The current study did not assess psychological characteristics; however, it may be that the individuals in the current study had increased stability in psychological factors that affect physical activity and inactivity. They also proposed that tracking during adolescence improves with stability of living arrangements: living within the same family and neighborhood and relating to the same friends over the years (1). Saskatoon has a relatively stable population; furthermore, the participants in the current cohort were from middle- to high-socioeconomic status families, which may result in more stable social characteristics. Individuals from the same elementary school also generally attend the same high school, keeping friend groups intact during the transition from childhood to adolescence. The psychological and social profile of the present cohort may help to explain the higher than expected tracking of physical activity.

The physiological (e.g., fat mass, BMI, aerobic capacity) changes that occur with the transition from childhood through adolescence have been well established (35), and the effect of these changes on the tracking of physical activity has been investigated (15,27). Other biological factors (e.g., ethnicity, body fatness, physical fitness), psychological parameters (e.g., type A behavior, other personality characteristics), adverse lifestyle behaviors (e.g., alcohol consumption, smoking), and motor performance/ability may also influence tracking of physical activity during adolescence and requires investigation (25). There is a need to conduct studies examining the tracking of physical activity in relation to psychological and social changes that occur during the transition from childhood to late adolescence.

This research suggests that, in females in early adolescence, controlling for differences in the timing of biological maturity may improve tracking of PA. This piece contributes to a body of research that supports the importance of biological maturity in adolescent PA (11,33,38). It may be that future interventions, especially in girls, are implemented based on BA groupings rather than CA. However, the viability of such programs would need to be investigated. The moderate-to-high tracking observed in the present study also supports the assertion that future adult physical activity might be improved through promoting physical activity in childhood and adolescence. This health promotion strategy would have long-term implications because physical activity in adulthood has been found to be related to a lower risk of developing serious illnesses such as cardiovascular disease, type 2 diabetes, and some cancers (4,6,12,23,44). A strength of this study is the length of follow-up and the number of repeated measures on each participant. Furthermore, because of the timing of the serial measures of height, we were able to measure the timing of APHV in the majority of the individuals enrolled in the study and thus had an accurate measure of biological maturity.

The present study has some limitations. Physical activity was assessed via a self-report survey (PAQ-A and PAQ-C). Although the questionnaires demonstrate good internal consistency and validity with several other evaluations of activity level (10), it is a self-report assessment and therefore has associated limitations (e.g., inaccurate recalling/reporting of PA). However, the use of the Physical Activity Questionnaire for Children/Adolescents allowed for multiple sampling within a period, which may not be possible with direct measures of physical activity such as accelerometers or direct observation. APHV was estimated from serial measures and used as our measure of biological maturation. Other measures of maturation such as development of secondary sex characteristics, especially in girls, may be important in predicting participation in physical activity. However, APHV and skeletal age are the only two measures of biological maturation, which are appropriate when comparing males and females biological maturity (31). Skeletal age involves subjecting participants to radiation, and this was not available in this cohort; therefore, APHV was the most appropriate method to assess the effect of biological maturation on the tracking of physical activity in both males and females. Because of the mixed longitudinal nature of the PBMAS study, the individuals in each tracking group differed slightly (because of differing ages of entry into the study and missed measurements). This resulted in an inability to statistically compare the CA and BA tracking coefficients for each 2-yr tracking group. A pure longitudinal study that followed the same individuals from late childhood to early adulthood would enable direct comparisons between the different tracking groups. Finally, data were collected approximately 10 yr ago. Although it is unlikely that the relationship between biological maturity and tracking of physical activity has changed in the preceding 10 yr, we do not have evidence to support or refute this.

In summary, variation in the timing of biological maturation within youth of the same CA might affect participation in PA and may partially explain the low tracking through adolescence. We examined the stability of PA over time from childhood to late adolescence when aligned on CA and BA scales and found moderate to high tracking of physical activity in both males and females aligned by either CA or BA. Accounting for differences in timing of biological maturity had little effect on tracking of PA in males; however, there seems to be higher point estimates for tracking in early adolescence in females when aligned by biological versus chronological age. This suggests that maturity may play a more prominent role in early adolescent PA participation in females.

The study was supported by funding from the Canadian Institute of Health Research.

The authors thank all participants and their families for their continued support.

The results of the present study to not constitute endorsement by the American College of Sports Medicine.

REFERENCES

1. Anderssen NB, Wold B, Torsheim T. Tracking of physical activity in adolescence. *Res Q Exerc Sport*. 2005;76(2):119–29.
2. Baggett CD, Stevens J, McMurray RG, et al. Tracking of physical activity and inactivity in middle school girls. *Med Sci Sports Exerc*. 2008;40(11):1916–22.
3. Baranowski T. Validity of self report of physical activity an information processing approach. *Res Q Exerc Sport*. 1998;59: 314–27.
4. Bassuk SS, Manson JE. Epidemiological evidence for the role of physical activity in reducing risk of type 2 diabetes and cardiovascular disease. *J Appl Physiol*. 2005;99(3):1193–204.
5. Baxter-Jones ADG, Eisenmann JC, Sherar LB. Controlling for maturation in pediatric exercise science. *Pediatr Exerc Sci*. 2005; 17:18–30.
6. Bernstein L, Patel AV, Ursin G, et al. Lifetime recreational exercise activity and breast cancer risk among black women and white women. *J Natl Cancer Inst*. 2005;97(22):1671–9.
7. Beunen GP, Lefevre J, Philippaerts RM, et al. Adolescent correlates of adult physical activity: a 26-year follow-up. *Med Sci Sports Exerc*. 2004;36(11):1930–6.
8. Campbell PT, Katzmarzyk PT, Malina RM, Rao DC, Perusse L, Bouchard C. Predicition of physical activity and physical work capacity (PWC150) in young adulthood from childhodd and adolescence with consideration of parental measures. *Am J Hum Biol*. 2001;13:190–6.
9. Cole TJ, Bellizzi C, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ*. 2001;320:1–6.
10. Crocker PR, Bailey DA, Faulkner RA, Kowalski KC, McGrath R. Measuring general levels of physical activity: preliminary evidence for the Physical Activity Questionnaire for Older Children. *Med Sci Sports Exerc*. 1997;29(10):1344–9.
11. Cumming SP, Standage M, Gillison F, Malina RM. Sex differences in exercise behavior during adolescence: is biological maturation a confounding factor? *J Adolesc Health*. 2008;42(5): 480–5.
12. Denmark-Wahnefried W, Rock CL, Patrick K, Byers T. Lifestyle interventions to reduce cancer risk and improve outcomes. *Am Fam Physician*. 2008;11:1573–8.
13. Drenowatz C, Esienmann JC, Pfriffer KA, Wickel EE, Gentile D, Walsh D. Maturity-related differences in physical activity among 10- to 12-year-old girls. *Am J Hum Biol*. 2010;22:18–22.
14. Figueiredo AJ, Goncalves CE, Coelho E, Silva MJ, Malina RM. Characteristics of youth soccer players who drop out, persist or move up. *J Sports Sci*. 2009;27:883–91.
15. Herman KM, Craig CL, Gauvin L, Katzmarzyk PT. Tracking of obesity and physical activity from childhood to adulthood: the Physical Activity Longitudinal Study. *Int J Pediatr Obes*. 2009;4(4):281–8.
16. Janz KF, Dawson JD, Mahoney LT. Tracking of physical fitness and physical activity from childhood to adolescence: the Muscatine study. *Med Sci Sports Exerc*. 2000;32(7):1250–7.
17. Janz KF, Witt J, Mahoney LT. The stability of children's physical activity as measured by accelerometry and self report. *Med Sci Sports Exerc*. 1995;27(9):1326–32.
18. Kimm SYS, Glynn NW, Kriska AM, et al. Longitudinal changes in physical activity in a biracial cohort during adolescence. *Med Sci Sports Exerc*. 2000;32(8):1445–53.
19. Klasson-Heggebo L, Andressen SA. Gender and age differences in relation to the recommendations of physical activity among Norwegian children and youth. *Scan J Med Sci Sports*. 2003;13: 293–8.
20. Kowalski KC, Crocker PR, Faulkner RA. Validation of the Physical Activity Questionnaire for Older Children. *Pediatr Exerc Sci*. 1997;9:174–86.
21. Kowalski KC, Crocker PR, Kowalski NP. Convergent validity of the Physical Activity Questionnaire for Adolescents. *Pediatr Exerc Sci*. 1997;9:342–52.
22. Kristensen PL, Moller NC, Korsholm L, Wedderkopp N, Andersen LB, Froberg K. Tracking of objectively measured physical activity from childhood to adolescence: the European youth heart study. *Scand J Med Sci Sports*. 2008;18(2):171–8.
23. Kushi LH, Byers T, Doyle C, et al. American cancer society guidelines on nutriation and physical activity for cancer prevention. Reducing the risk of cancer with healthy food choices and physical activity. *CA Cancer J Clin*. 2006;56:254–81.
24. Malina RM. Tracking of physical activity across the lifespan. *Pres Counc Phys Fit Sports Res Dig*. 2001;3(14):1–8.
25. Malina RM, Bouchard C, Bar-Or O. *Growth, Maturation and Physical Activity*. 2nd ed. Chicago (IL): Human Kinetics; 2004. p. 470–4.
26. Matton LM, Thomis M, Wijndaele K. Tracking of physical fitness and physical activity from youth to adulthood in females. *Med Sci Sports Exerc*. 2006;38(6):1114–20.
27. McMurray RG, Harrell JS, Bangdiwala SI, Hu J. Tracking of physical activity and aerobic power from childhood through adolescence. *Med Sci Sports Exerc*. 2003;35(11):1914–22.
28. Nyberg G, Ekelund U, Marcus C. Physical activity in children measured by accelerometry: Stability over time. *Scand J Med Sci Sports*. 2009;19(1):30–5.
29. Riddoch CJ, Mattocks C, Deere K, et al. Objective measurement of levels of and pattern of physical activity. *Arch Dis Child*. 2007; 92(11):963–9.
30. Sherar LB, Baxter-Jones ADG, Faulkner RA, Russell KW. Do physical maturity and birth date predict talent in male youth ice hockey players? *J Sports Sci*. 2007;25:879–86.
31. Sherar LB, Baxter-Jones ADG, Mirwald RL. Limitations to the use of secondary sex characteristics for gender comparisons. *Ann Hum Biol*. 2004;31:586–93.
32. Sherar LB, Cumming SP, Eisenmann JC, Baxter-Jones ADG, Malina RM. Adolescent biological maturity and physical activity: biology meets behavior. *Pediatr Exerc Sci*. 2010;22:332–49.
33. Sherar LB, Esliger DW, Baxter-Jones ADG, Tremblay MS. Age and gender differences in youth physical activity: does physical maturity matter? *Med Sci Sports Exerc*. 2007;39(5):830–35.
34. Summers-Effler E. Little girls in women's bodies: social interaction and the strategizing of early breast development. *Sex Roles*. 2004;51:29–44.
35. Tanner JM. *Foetus into Man: Physical Growth from Conception to Maturity*. London (UK): Castlemead Publications; 1989. p. 6–23.
36. Telama R, Yang X, Viikari J, Valimaki I, Wanne O, Raitakari O. Physical activity from childhood to adulthood: a 21-year tracking study. *Am J Prev Med*. 2005;28:267–73.
37. The International Society for the Advancement of Kinanthropometry (ISAK). *International Standards for Anthropometric Assessment*. Underdale, SA (Australia): ISAK; 2001. p. 51–6.

38. Thompson AM, Baxter-Jones ADG, Mirwald RL, Bailey DA. Comparison of physical activity in male and female children: does maturation matter? *Med Sci Sports Exerc*. 2003;35(10): 1684–90.
39. Trost SG, Pate R, Sallis JF, et al. Age and gender differences in objectivity measured physical activity in youth. *Med Sci Sports Exerc*. 2002;34(2):350–4.
40. Trudeau F, Laurencelle L, Shephard RJ. Tracking of physical activity from childhood to adulthood. *Med Sci Sports Exerc*. 2004; 36(11):1937–43.
41. Twisk JW, Kemper HC, Van Mechelen W. Prediction of cardiovascular disease risk factors later in life by physical activity and physical fitness in youth: general comments and conclusions. *Int J Sports Med*. 2002;23(Suppl 1):S44–9.
42. Van Mechelen W, Kemper HCG. Habitual physical activity in longitudinal perspective. In: Kemper HCG, editor. *The Amsterdam Growth Study*. Champaign (IL): Human Kinetics; 1995. p. 135–58.
43. Van Mechelen W, Twisk JW, Post GB, Snel J, Kemper HCG. Physical activity of young people: the Amsterdam Longitudinal Growth and Health Study. *Med Sci Sports Exerc*. 2000;32(9): 1610–6.
44. Wessel TW, Arant CB, Olson MB, et al. Relationship of physical fitness versus body mass index with coronary artery disease and cardiovascular events in women. *JAMA*. 2004;292:1179–87.