Original Research Article

Maturity-Related Differences in Physical Activity Among 10- to 12-Year-Old Girls

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ABSTRACT Besides environmental and psycho-social factors explaining the variation in physical activity levels during adolescence, some evidence suggests that biological processes are involved in regulating habitual daily physical activity and energy expenditure. The purpose of this study was to examine the influence of biological maturity status on physical activity. Chronological age, standing height, sitting height, and body mass were measured cross-sectionally in 268 girls, aged 9.5 to 11.5 years. Biological maturity groups (Early, Average, Late) were created according to estimated age at peak-height-velocity (estAPHV). Habitual physical activity was determined with a pedometer (Yamax Digiwalker SW-200) over a 7-day period. Differences in steps/day across maturity groups were examined by ANCOVA, controlling separately for time the pedometer was worn, leg length, and body mass. Mean pedometer steps/day was 10,822 ± 2,639. As expected, body size varied by maturity status (e.g., early > average > late). Significant maturity group differences were found with early maturing girls showing lower activity levels compared to average or late maturers. These differences remained after controlling for time the pedometer was worn and leg length; however, the differences were no longer significant when controlling for body mass. The results suggest that biological maturity status influences physical activity levels in girls between 10 and 12 years of age but the relationship is not independent of body mass. Further research is needed to establish the complex inter-relationships among adiposity, biological maturation, and energy expenditure during puberty. Am. J. Hum. Biol. 22:18–22, 2010.

The age-related pattern in the habitual physical activity level of boys and girls has been well studied (Andersen et al., 2003; Kohl and Hobbs,1998; Malina et al., 2004; Trost et al., 2002). In brief, boys generally possess higher physical activity levels than girls throughout childhood and adolescence. In both sexes, physical activity levels decrease with age, especially during adolescence, but the decline in physical activity seems to be more pronounced in girls (Sallis et al., 2000; Trost et al., 2002). At this time, however, the specific cause(s), and even some of the determinants, of the age-related decline remain uncertain.

Most studies addressing the age- and sex-associated variation in physical activity levels in children and adolescents focus on environmental and psycho-social aspects (Davison et al., 2003; Di Lorenzo et al.,1998; Ferreira et al., 2007; Sallis et al., 2000), while biological aspects have only sparsely received attention. However, there is some evidence supporting the assumption that intrinsic, biological processes are involved in regulating habitual daily physical activity and energy expenditure (Rowland, 1998; Thorburn and Proietto, 2000). A strong line of support of this aspect is the fact that physical activity declines at the time of biological maturation across all animal species (Ingram, 2000; Rowland, 1998). In humans, the decline in physical activity during adolescence may also be reflecting changes in biological maturity status within- and between-individuals, because the timing and tempo of biological maturation varies across human beings. In turn, biological maturation affects both psycho-social and biological factors that may ultimately influence physical activity levels.

Although the age- and sex-differences in physical activity are well recognized, few studies have considered the influence of biological maturity status on physical activity (Baker et al., 2007; Wickel and Eisenmann, 2007; Wickel et al., in press), while other studies focus on sex differences in physical activity levels when aligned by biological age rather than chronological age (Sherar et al., 2007; Thompson et al., 2003). Given that the decline in physical activity during adolescence is more pronounced in girls and the well recognized potential benefits of physical activity concerning bone health and other chronic disease risk factors in females, examining the possible reasons for the aforementioned decline in physical activity in girls is of particular interest.

Recent studies (Baker et al., 2007; Wickel and Eisenmann, 2007; Wickel et al., in press) provide some evidence that early maturing girls possess lower physical activity levels than later maturing girls. However, these studies had methodological limitations. More specifically, Baker et al., (2007) used a composite score to create only two maturity groups (early vs. later), and in our previous studies (Wickel and Eisenmann, 2007; Wickel et al., in press) only

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a small sample of girls were categorized as late maturers. As the decline in physical activity begins near the onset of puberty, it is important to consider physical activity at earlier ages and across all maturity groups. Therefore, the purpose of this study was to add to the breadth of this topic by examining the influence of biological maturity status on habitual physical activity among 9.5- to 11.5-year-old girls.

METHODS

Subjects

Participants included 268 girls between 9.5 and 11.5 years of age from two Midwestern U.S. communities (Lakeville, MN and Cedar Rapids, IA). Subjects were recruited for an intervention study (Eisenmann et al., 2008) but the values reported herein are taken from baseline (preintervention) testing and thus were not influenced by the intervention. Data collection occurred in September 2006. Written assent from each subject and consent from her primary caregiver was obtained prior to participation in the study. The study protocol was approved by the University of Minnesota's Human Subjects Review Board and is in accordance with the Declaration of Helsinki.

Anthropometry

Chronological age was calculated by subtracting the participant's date of birth from the observation date. Standing height, sitting height, and body mass were measured following standard procedures (Malina, 1995). Standing height and sitting height were measured using a portable stadiometer (Seca Road Rod). Estimated leg length was calculated by subtracting sitting height from standing height. Body mass was measured using a strain gauge scale (Lifesource MD) and the body mass index (BMI, kg/m^2) was calculated from measurements of standing height and body mass.

Maturity status

Given the methodological and practical limitations of assessing biological maturation by skeletal, somatic, or sexual indicators, Mirwald et al. (2002) developed sex-specific equations to estimate the number of years away from peak height velocity (PHV), and refer to this as the maturity offset. Using anthropometric data (stature, sitting height, leg length, body mass and chronological age) from the observation date (i.e., cross-sectional), the prediction equation [Eq. (1) following] offers a noninvasive and feasible approach to estimate maturity status. In the original paper, the validity coefficient between skeletal age and maturity offset was 0.83 (Mirwald et al., 2002), suggesting acceptable agreement between the two approaches to estimate maturity status.

$$
\begin{aligned}
\text{Maturity offset} = & -9.376 + 0.0001882 \\
& \times (\text{leg length} \times \text{sitting height}) \\
& + 0.0022\ (\text{age} \times \text{leg length}) \\
& + 0.005841\ (\text{age} \times \text{sitting height}) \\
& - 0.002658\ (\text{age} \times \text{weight}) \\
& + 0.07693\ (\text{weight/height}) \qquad (1)
\end{aligned}
$$

Although the maturity offset does not provide an indication of tempo, it does provide an indication of timing between individuals to allow for comparisons between biological maturity groups. The maturity offset can be used as a continuous variable (e.g., -1.2 years from PHV) or it can be used to estimate the age at PHV (estAPHV) (estAPHV = chronological age—maturity offset). In the latter instance, comparisons between biological maturity groups (e.g., early, average, and late maturers) can be examined. For the purpose of this study, average maturing girls had an estAPHV between 11.2 and 12.2 years of age. These values were obtained using the mean estAPHV (11.7 years) of the sample. Girls with an estAPHV $>$12.2 years were considered late maturers, whereas girls with an estAPHV $<$11.2 years were considered early maturers.

Habitual physical activity

Habitual, free-living physical activity was assessed by a pedometer (Digiwalker SW-200), which has been found suitable for research purposes (Jago et al., 2006; Welk et al., 2000). The subjects were given instructions on wearing the pedometer during the day and the accuracy of the pedometer was checked prior to data collection. Participants recorded the time the pedometer was worn and the number of steps accumulated each day over a 7-day period. Previous research supports a 4-day monitoring period to determine habitual physical activity (Trost et al., 2005). In addition, it is necessary to account for potential bias between weekend and weekday step counts. For these reasons, participants were included in the analysis only if they had at least 4 days (3 weekdays and 1 weekend) when the pedometer was worn for at least 10 h. The first day the pedometer was worn was also excluded from further analysis to avoid possible reactivity of wearing a pedometer.

Statistical analysis

Descriptive statistics were calculated for the anthropometric and physical activity characteristics of the sample. Maturity-group differences were initially tested using univariate analysis of variance (ANOVA). Further analyses used ANCOVA controlling separately for pedometer time on body, leg length and BMI as these variables may impact step frequency or physical activity. Leg length was considered as a covariate because the main outcome was expressed as steps per day, and individuals with longer legs cover the same distance with fewer steps (Eisenmann and Wickel, 2005). BMI was subsequently used as a covariate given its relationship with physical activity level (Eisenmann et al., 2002). All statistical analysis was conducted using SPSS (Version 16.0).

RESULTS

Physical characteristics and physical activity levels of the participants are shown in Table 1. The majority (n = 183, 68.3%) of the participants were classified as average maturers and the remaining were classified as early maturers (n = 33, 12.3%) or late maturers (n = 52, 19.4%). As expected, significant maturity group differences were shown for height ($F(2, 265) = 77.59$, $P = 0.001$) and body mass ($F(2, 265) = 97.60$, $P = 0.001$). Tukey post hoc tests showed significant differences between all maturity groups (P = 0.001) for these variables with early

TABLE 1. Descriptive characteristics of girls by maturity status

Variable	Early mature (n = 33)	Avg. mature (n = 183)	Late mature (n = 52)	Total sample (n = 268)
Chronolog. Age (yrs.)	10.3 (±0.4)	10.2 (±0.5)	10.5 (±0.4)	10.3 (±0.5)
Est. age at PHV (yrs.)[a]	10.9 (±0.2)	11.7 (±0.3)	12.4 (±0.2)	11.7 (±0.5)
Standing height (cm)[a]	150.9 (±5.4)	142.0 (±5.8)	135.4 (±4.8)	141.8 (±7.0)
Leg length (cm)[a]	71.6 (±4.1)	67.7 (±3.8)	65.1 (±3.4)	67.7 (±4.2)
Body mass (kg)[a]	56.2 (±8.3)	37.3 (±6.5)	29.4 (±4.1)	38.1 (±9.8)
BMI (kg/m^2)[a]	24.7 (±3.5)	18.5 (±2.7)	16.0 (±1.8)	18.8 (±3.6)

[a]Significant differences between all groups ($P < 0.05$).

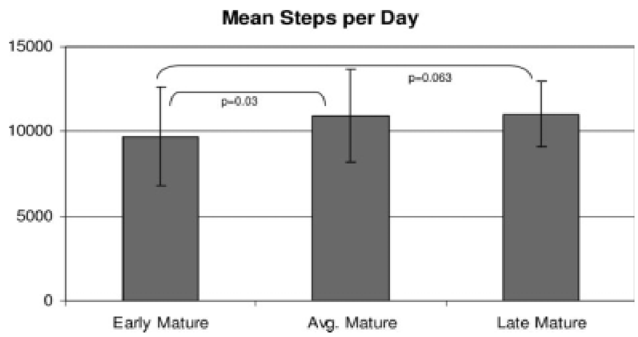

Fig. 1. Mean Steps per day among early, average, and late maturing girls. *x-axis:* 3 Maturity groups. *y-axis:* Number of steps per day (±SD) of 3 Maturity groups. *P*-values from ANOVA, Tukey post-hoc tests.

maturing girls being heavier and taller than average and late maturing girls. Accordingly, all maturity groups differed significantly in BMI ($F(2, 265) = 109.42$, $P = 0.001$) and leg length ($F(2, 265) = 29.89$, $P = 0.001$). The mean BMI of the early maturing girls was >95th percentile. Average maturers' mean BMI approximated the 75th percentile and the BMI of late maturers approximated the 30th percentile. No significant group differences occurred for pedometer time worn ($F(2, 265) = 2.266$, $P = 0.106$).

The mean steps per day for the entire sample was 10 822 (± 2639 steps per day). Mean steps per day differed significantly between maturity groups ($F(2, 265) = 3.44$, $P = 0.04$). Early maturing girls showed significantly lower mean steps per day compared with average maturers ($P = 0.03$) and there was a trend toward significance when early maturers were compared with late maturers ($P = 0.06$)(see Fig. 1). These differences remained significant when controlling for time the pedometer was worn ($F(2, 264) = 3.149$, $P = 0.045$) and for leg length ($F(2, 264) = 3.65$, $P = 0.03$); however, when controlling for BMI, differences in mean steps per day by maturity group were no longer significant ($F(2, 264) = 1.33$, $P = 0.27$).

DISCUSSION

Although the age-related decline in physical activity among girls is well known, few studies have considered the influence of biological maturity status. Our results indicate that early maturing girls between 10 and 12 years of age display lower physical activity levels (pedometer steps/day) than average or late maturing girls even when accounting for leg length. However, the differences in steps per day were no longer significant when controlling for BMI, suggesting that body weight and fatness influence physical activity in early maturing girls.

These results are in accordance with previous findings. Using the same methodology as the current study, Wickel and Eisenmann, (2007) found a trend toward lower physical activity levels among early maturers compared with average and late maturers in an older (13- to 14-year-old) sample of girls. Similarly, Baker et al., (2007) showed that physical activity levels of early maturing girls were 13% less than those of late maturers. This study used a longitudinal design and followed the girls from 11 to 13 years of age. Accelerometry as well as self-reports were used to measure physical activity and maturity status was determined by a composite score of blood estradiol levels, Tanner breast stage criteria, and parental report of pubertal development. Results from a study by Riddoch et al., (2007) also show a similar trend in 11-year-old English girls. In this study, physical activity levels were compared between five maturity groups determined by self-reported pubertal stage. Taken together, these findings support the argument that biological maturity status of female adolescents influences physical activity level.

Although we are considering biological maturity status to be a biological determinant of physical activity, it seems that both psycho-social and biological aspects could potentially influence the maturity-associated variation in physical activity among females. Previous research has focused on psycho-social aspects related to the age-related decline in physical activity of adolescent girls. For example, Baker et al. (2007) addressed the importance of body esteem, perceived skill, and parent or peer support for physical activity in girls. They reported that early maturing girls tend to have a poorer body image, which lowers their enjoyment in physical activity and thus hinders engagement in physical activity. Furthermore, the dynamic physical changes of puberty (i.e., increased fat mass, breast development, broadening of hips, etc.) might affect girls' ability and willingness to participate in sports. Monsma et al. (2008) addressed the issue of social physique anxiety and showed that even in lean female athletes the body image can be disrupted possibly causing reduced self-esteem and lower motivation for physical activity and sport. It is also suggested that parents might show lower support for early maturers, because they want to implement a more adult-like behavior in these girls (Baker et al., 2007). Peer support could decrease as well, since early maturing girls tend to socialize with older peers, who generally display lower levels of physical activity because of other interests and possibly more school-related work (Baker et al., 2007).

The differences in physical activity by maturity group could also be due to biological factors (Lightfoot, 2008; Rowland, 1998). To date, few studies have addressed the impact of biological factors on physical activity levels in adolescence or in general. Lightfoot (2008) suggests that a central nervous system "activity-stat" and changes in various physiological substances (e.g., hormones) or structures (e.g., estrogen/testosterone pathways) need to be considered when examining individual physical activity levels. Indeed, sex steroid and growth hormones, neuropeptides, and appetite-related hormones affect physical activity/energy expenditure and energy balance (Novak and Levine, 2007). For example, ghrelin has been shown to decrease physical activity and leptin has been shown to increase physical activity (Tou and Wade, 2002). Orexin, a neuropeptide sensitive to leptin, has also been shown to increase physical activity (Novak and Levine, 2007). However, the age- and pubertal-related changes in these biomarkers along with the changes in body composition are complex and not understood at this time. For example, leptin has been shown to increase during puberty (Shalitin and Phillip, 2003), which is in contrast to the lower levels of physical activity in earlier maturing girls. Increasing levels of leptin, however, are expected during puberty, because leptin levels are positively correlated with body fatness. Kaplowitz (2008) argues that an earlier onset of puberty is caused by a higher body fatness, rather than that early onset of puberty causes an increase in body fat. Besides a change in body composition, it has also been shown that sensitivity to certain hormones changes during puberty (Malina et al., 2004). Apter (2003) has shown that concentration of the leptin binding protein in the blood (identical with soluable leptin receptor, sOB-R) decreases from birth until puberty. If sensitivity to leptin decreases during puberty there would be no increase in physical activity despite higher leptin levels. Further, higher body fatness has been shown to be related to lower physical activity levels (Kimm et al., 2005: Sulemana et al., 2006).

As for ghrelin, there is a decline throughout childhood and adolescence until mid-puberty (Whatmore et al., 2003). This also seems to be in contrast to the findings that ghrelin is supposed to play concerning physical activity levels. Considering the inverse relationship between ghrelin and body fatness, a decline throughout puberty is not surprising (Chanoine, 2005). Popovic and Duntas (2005) argue that ghrelin levels are rather compensatory than causal concerning the development of obesity. In relation to physical activity, Jürimäe et al., (2007) showed that mean plasma ghrelin levels were significantly higher in active pubertal girls compared with sedentary girls. The authors suggested that the increased energy expenditure in active girls is responsible for higher ghrelin levels, because it has been shown that ghrelin stimulates appetite and plays a role in glucose metabolism (Chanoine, 2005). The role of ghrelin concerning dietary intake and physical activity, however, is not well defined (Jürimäe et al., 2007) and current data suggests that ghrelin might be more closely related to body composition, which as previously mentioned, is related to physical activity levels (Dimaraki and Jaffe, 2006). Further, there seems to be an inverse relationship between ghrelin and leptin concentrations, but the exact mechanisms still remain to be investigated (Popvic and Duntas, 2005). Therefore, further investigation, especially using a longitudinal study design, is needed to gain further insights into biological constraints that influence physical activity during puberty.

Previous studies, as well as results shown in this paper, however, highlight the importance of body weight and body composition when studying physical activity levels. During puberty, changes in the sensitivity of the hypothalamic-pituitary axis occur and it has been argued that an overly sensitive hypothalamic-pituitary-adrenal axis may disrupt the hormonal mileau of some of the key hormones influencing both adiposity and potentially physical activity (Roemmich and Rogol, 1999). Tou and Wade, (2002) reported a 51% to 70% reduction in motor activity in obese mice, and these authors suggest that "decreased activity is a response rather than a contributor to weight gain" (p. 588). The influence of biological factors and environmental constraints or psycho-social aspects on body weight and body composition as well as on physical activity needs further investigation.

The current study could have been strengthened by a larger and more diverse sample, and more precise measures of physical activity and maturity status. The sample was relatively small and consisted mainly of Caucasians. The small sample size of early and late maturing girls is probably the reason for the nonsignificant differences in physical activity between these two groups. Although pedometers were used to assess physical activity, neither the information on the intensity or pattern of physical activity, nor the total energy expenditure could be quantified. The limitations of assessing biological maturity status cross-sectionally are well known, including social ethics (secondary sex characteristics) and exposure to radiation (skeletal maturity). Therefore, we and others have begun using the maturity offset as a noninvasive indicator. Mirwald et al. (2002) have demonstrated the validity of this equation, and the average age at PHV (11.7 years) in the current study is in accordance with the literature (Malina et al., 2004).

In summary, the results show that early maturing girls between 10 and 12 years of age display lower physical activity levels than average or late maturing girls. However, the differences are not independent of BMI. The findings can be supported by both the argument that biological and psycho-social factors acting during adolescence impact physical activity levels perhaps through body size and composition. Future research should use a longitudinal approach, which includes a thorough investigation of the psycho-social and biological factors associated with biological maturation and their role on physical activity levels in adolescent girls.

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