TITLE PAGE

Biological maturity and primary school children's physical activity: Influence of different physical activity assessment instruments

ABSTRACT

Biological maturation may attenuate hypothesised sex differences in children's physical activity but overall the evidence for this is equivocal. The study investigated how the selection of different physical activity assessment instruments affects the detected relationship between biological maturation and late primary school children's physical activity. One hundred and seventy five children (97 girls) aged 10.6 ± 0.3 y completed the PAQ-C self-report questionnaire and wore ActiGraph GT1M accelerometers for 5 consecutive days. Maturity status was predicted by estimating attainment of age at peak height velocity. Following initial exploration of sex differences in PAQ-C (t-test) and multiple ActiGraph outcome variables (MANOVA), the influence of maturity status was controlled using ANCOVA and MANCOVA. Unadjusted analyses revealed that boys were significantly more active than girls according to the PAQ-C ($p < 0.0001$, $d = 0.52$) and ActiGraph ($p < 0.0001$, $d = 0.36 – 0.72$). After controlling for maturity status the differences in PAQ-C scores increased ($p = 0.001$, $d = 0.64$), but significant differences disappeared for ActiGraph data ($p = 0.36$, $d = 0.17 – 0.33$). The detected relationship between maturity status and late primary school children's physical activity is dependent on physical activity assessment tool employed, reflecting the different aspects of physical activity captured by the respective measures.

Keywords: maturation, child, methods, gender

INTRODUCTION

The health benefits of young people's regular involvement in moderate-to-vigorous bouts of physical activity include normal growth and development, adaptive psychological and behavioural functioning, the maintenance of energy balance, and the minimization of cardiovascular disease risk factors (Cumming & Riddoch, 2009). The reported prevalence of youth physical activity varies depending on assessment method employed. According to a large-scale study of objectively assessed physical activity only 2.5% of English 11-12 y olds met current guidelines (NICE, 2009) of at least 60 minutes of daily moderate-to-vigorous intensity physical activity (MVPA) (Riddoch et al., 2007). Conversely, nationally representative English self-report data of primary school children reported that two-thirds of them achieved the recommendation (Sproston & Primatesta, 2003). Irrespective of physical activity assessment method boys are consistently reported to be more physically active than girls (Andersen et al., 2006; Riddoch et al., 2007; Trost et al., 2002). These sex differences in physical activity are attributed to a complex interplay between biological, psycho-social, cultural, and environmental factors (Eisenmann & Wickel, 2009; Malina, Bouchard, & Bar-Or, 2004).

Biological maturation is one factor thought to influence young people's physical activity participation. Maturation refers to the level or extent to which a child has progressed to the mature state and can be viewed in terms of timing (i.e., the time at which certain maturational events occur) or tempo (i.e., rate of maturation) (Malina et al., 2004). The effects of maturation may mask or be greater than the effects of exposure to environmental factors designed to increase physical activity or enhance health, such as intervention protocols (Baxter-Jones, Eisenman, &

Sherar, 2005). Thus, maturity status should be an important consideration in research examining or comparing boys' and girls' physical activity, or the health benefits associated with physical activity in youth.

Comparisons of physical activity in boys and girls are commonly based on chronological age, often because studies sample from school settings where children are grouped according to grade level. However, maturity status can vary considerably among youth of the same chronological age as it does not advance in unison with the calendar (Malina et al., 2004). Studies investigating the effect of maturity status on youth physical activity have generally produced inconsistent results. Some studies have reported the elimination or attenuation of sex differences in physical activity when the effect of maturation was controlled (Sherar, Esliger, Baxter-Jones, & Trembaly, 2007; Thompson, Baxter-Jones, Mirwald, & Bailey, 2003), whilst others have noted no differences in physical activity between boys and girls at different stages of maturity (Drenowatz et al., 2009; Wickel, Eisenmann, & Welk, 2009).

The most common explanation as to why maturation acts as a confounding factor in sex comparisons of physical activity centres around the observation that humans, male or female, become less active as they progress towards the mature state. As girls generally mature approximately two years in advance of boys (Malina et al., 2004) it follows that girls should be less physically active when compared against boys of the same chronological age The consequences of advanced maturation initially centre on biological changes, many of which may influence involvement in physical activity through changes in functional capacity and/or changes in psycho-social factors (Sherar, Cumming, Eisenmann, Baxter-

Jones, & Malina, in press), such as self-perceptions (Fairclough & Ridgers, 2010). Further, maturity related changes in body size, physique, and/or secondary sex characteristics may hold social stimulus value for significant others (e.g., peers, parents, teachers, coaches) (Petersen & Taylor, 1980), influencing the nature of interpersonal relations that may be relevant to participation in various forms of physical activity (Sherar et al., in press). For example, the physical characteristics of young gymnasts are closely related to athlete perceptions of coach behaviour with smaller and lighter gymnasts reporting higher levels of support, and instruction, and less punishment (Cumming, Eisenmann, Smoll, Smith, & Malina, 2006). Due to the sex-specific timing of maturation girls will generally experience these changes earlier than boys which may consequently manifest themselves as barriers to physical activity engagement (Sherar et al., 2009).

Research investigating the effects of maturity status on youth physical activity has most often involved adolescent girls (Sherar et al., 2009) using either self-report (Cumming, Standage, Gillison, & Malina, 2008) or objective (Sherar et al., 2009) assessment of physical activity. The use of different physical activity assessment tools may be a contributory reason for inconsistent results in studies investigating the relationship between maturation and physical activity, and is considered an issue worthy of further investigation (Sherar et al., in press).

Though most studies of this nature have focused on adolescents, youth physical activity is thought to decline prior to puberty (Malina et al., 2004), with one study observing the largest reductions in boys' and girls' activity to occur between ages 8 and 9 years (Sherar et al., 2007). Moreover, in children aged 5 to 8 years sex differences in physical activity were attenuated when maturity status was controlled (Eaton & Piklai Yu, 1989). Therefore, it is possible that maturity status influences the physical activity of pre- and peri-pubertal children as well as more maturationally advanced youth. What is not clear is how this influence is impacted on by method of physical activity assessment. Consistent with the recommendations of Sherar et al., (in press) this study aimed to investigate whether different physical activity assessment instruments affect the impact of maturity status on physical activity among pre- and peri-pubertal children.

METHODS

Participants

Data were gathered from children aged 10-11 years from a large north-west English town. Following ethical approval from the University Ethics Committee all primary schools in the town were informed about the project and invited to participate. Of the schools that expressed an interest a random number generator was used to randomly select one from each of 10 geographically representative township areas. Prior to the project commencing two schools withdrew and due to time pressures were not replaced. The project was verbally explained to all children in school Year 6 (n = 307) in the remaining 8 schools, which were situated in urban and suburban areas. The mean number of children enrolled in each school was 347.8 ± 143.8, ranging from 149 in the smallest school to 517 in the largest one. The proportion of children eligible for free school meals in these schools averaged 7.8 ± 3.6% (range = 3.4% to 15.1%) which was less than the national average of 16.1%. Completed parental consent and child assent were returned with home postcodes from 230 children (116 girls; 74.4% response rate) whose ethnic origin was predominantly white British. Data were collected in one school per week between October and December 2008.

Socio-economic status

Socio-economic status was calculated using the 2007 Indices of Multiple Deprivation which are comprised of seven domains of deprivation which relate to income, employment, health, education, housing, environment, and crime (DepartmentforCommunitiesandLocalGovernment, 2008). Deprivation scores were derived from the children's main home postcodes using the National Statistics Postcode Directory database (Census.ac.uk, 2008). Higher socio-economic status was represented by lower deprivation scores.

Anthropometry

Chronological age was calculated by subtracting each child's date of birth from the measurement date. Stature and sitting height were measured to the nearest 0.1 cm using a portable stadiometer (Leicester Height Measure, Seca, Birmingham, UK). Leg length was calculated by subtracting sitting height from stature. Body mass was measured to the nearest 0.1 kg using calibrated scales (Seca, Birmingham, UK). All measurements were taken by trained research staff using standard procedures (Lohman, Roche, & Martorell, 1988).

Maturity status

Somatic maturity status was estimated by predicting years from attainment of age at peak height velocity (APHV). APHV reflects the age at maximum growth rate in stature during adolescence. Years from APHV for each child were predicted using sex-specific regression equations that included stature, sitting height, leg length, chronological age and their interactions (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). This method is simple, non-invasive, and has demonstrated acceptable agreement when correlated against skeletal age (r = 0.83) (Mirwald et al., 2002).

Physical activity

Physical activity was objectively measured for five consecutive days (Friday through Tuesday) using ActiGraph accelerometers (Model GT1M, ActiGraph LLC, Pensacola, FL). The ActiGraph is a common tool to assess the volume and intensity of physical activity, and it has previously been validated with children (Trost et al., 1998). The children wore the ActiGraph over the right hip using a waist mounted nylon belt. To distinguish between wear time and sleep time children were also given a log sheet and asked to record when the ActiGraph was put on in the morning and removed at night before bed, and any other times when the monitor was removed (e.g., during showering, contact sports, etc). Movement counts were recorded every 5 seconds. At the end of the data collection period the ActiGraphs were downloaded using Actlife software (ActiGraph LLC, Pensacola, FL). This produced individual files containing movement counts recorded at each 5 second interval. These files were initially checked for compliance to the monitoring protocol using customised software (MAHUffe; www.mrc-epid.cam.ac.uk). Sustained 20 minute periods of zero counts were deemed to indicate that the ActiGraph had been removed, and total 'missing' counts for those periods represented the duration that monitors were not worn (Catellier et al., 2006). For inclusion in the analyses each child was required to have produced counts for ≥ 629 minutes and ≥ 605 minutes on each week day and weekend day, respectively. These figures represented 'non-missing' counts for at least 80% of a standard measurement day, which was defined as the length of time that at least

70% of the sample wore the monitor (Catellier et al., 2006). The log sheets of children with less than the minimum daily wear time were inspected to identify when the ActiGraphs had been removed for legitimate reasons due to participation in sports or water-based activities. To avoid unnecessarily excluding children from the analyses, where appropriate, daily wear time was manually adjusted upwards to include the time when the ActiGraphs had legitimately been removed. Data from children with at least 3 valid measurement days (including at least 1 weekend day) were then retained for further analysis as this has previously been deemed a reliable minimum wear time for children of this age (Mattocks et al., 2008). Fifty-five children (19 girls) did not meet the minimum wear time criteria and so were excluded from subsequent analyses. The number of minutes of moderate (MPA) and vigorous (VPA) physical activity were calculated using cut-points of 2000 and 4000 counts • min^{-1}, respectively. These cut-points have previously been used in this age group to study associations between physical activity intensity and metabolic outcomes (Ekelund et al., 2007) and were converted to counts • 5 s^{-1} prior to analysis. Accumulated time spent in MPA and above was defined as MVPA. Total volume of daily activity was calculated using counts • min^{-1}.

Self-reported physical activity was assessed using the Physical Activity Questionnaire for Older Children (PAQ-C) (Crocker, Bailey, Faulkner, Kowalski, & McGraith, 1997). The PAQ-C is a 7-day recall instrument that has been used extensively (Niven, Fawkner, Knowles, & Stephenson, 2007; Thompson et al., 2003) and has demonstrated evidence of being a valid and reliable measure of general physical activity during the primary school week (Crocker et al., 1997). From the nine PAQ-C items a measure of physical activity is calculated on a 1-5 scale (1 = little or no activity, through 5 = very high levels of activity). The week after ActiGraphs were worn the PAQ-C was completed in a classroom setting following instructions from the research staff.

Data analysis

Preliminary Kolmogorov-Smirnov analysis highlighted that not all data were normally distributed. Natural log transformation was applied to normalize the data and subsequent analyses were performed using the transformed values. For presentation purposes untransformed data are reported. Descriptive statistics were calculated for age, anthropometric measures, and years from APHV. For the main analyses an independent *t*-test assessed sex differences in self-reported physical activity. Mean counts • min^{-1} and mean weekly minutes in MPA, VPA, and MVPA were compared between boys and girls using MANOVA. These analyses were then repeated with years from APHV included as a covariate (ANCOVA and MANCOVA) to assess the influence of maturity status on PAQ-C and objectively assessed physical activity, respectively. Effect sizes (*d*) were calculated using the weighted pooled estimate of the *SD* (Hedges, 1981). Alpha was set at $P < 0.05$ for all analyses which were performed using SPSS version 17 (SPSS, Chicago, IL).

RESULTS

Boys' and girls' descriptive characteristics for chronological age, body size, body mass index (BMI), maturation, and socio-economic status are presented in Table 1. The children were well matched though girls were 1.5 years closer to APHV than boys. Boys (720.8 ± 101.5 minutes) and girls (721.1 ± 76.4 minutes) wore the ActiGraphs for similar amounts of time each day . There were no significant differences in age, stature, years from APHV, PAQ-C, or MPA between the included and excluded children based on Actigraph wear time. The excluded boys had significantly lower body mass (p = 0.026) and BMI values (p = 0.045) than the excluded girls and included children. Moreover, the excluded boys spent significantly more time in VPA (p = 0.004), MVPA (0.026), and accumulated significantly more ActiGraph counts • min^{-1} (p = 0.003) than the rest of the sample.

TABLE 1 ABOUT HERE

Boys reported significantly higher PAQ-C scores than girls ($t_{173} = 4.03$, $P < 0.0001$, $d = 0.52$; Table 2). This moderate effect size increased by 23% when years from APHV was included as a covariate ($F_{1, 172} = 12.24$, P =0 .001, $d = 0.64$; Table 3). Analysis of the ActiGraph data confirmed that the boys were significantly more active than the girls (Wilks'Λ = .82, $F_{4, 170} = 9.15$, $P < 0.0001$). Follow-up univariate ANOVAs revealed significant sex differences for MPA, VPA, MVPA, and counts • min^{-1} (Table 2). The largest effects were for MPA ($d = 0.72$) and MVPA ($d = 0.67$). The recommended 60 minutes of MVPA per day were achieved by 63.2% of boys and 36.8% of girls. The significant sex differences in objectively assessed physical activity disappeared when years from APHV was co-varied into the analysis (Wilks'Λ = .98, $F_{4, 169} = 1.10$, $P = 0.36$). Adjusted counts • min^{-1} and minutes spent in the different physical activity intensities are presented in Table 3. Effect sizes for sex-differences in objectively assessed physical activity reduced by an average of 54% when the effect of maturity was controlled.

TABLES 2 & 3 ABOUT HERE

DISCUSSION

When the physical activity of boys and girls of the same chronological age was compared boys reported significantly more activity, and engaged in more objectively assessed activity than girls. The moderate effect sizes for PAQ-C, MPA, and MVPA suggest that these differences in particular were most meaningful. Though statistically significant, sex differences in VPA and counts • min^{-1} produced smaller effect sizes suggesting that boys and girls engaged in more comparable volumes of total activity and minutes of high intensity physical activity. The sex difference in PAQ-C scores of 0.39 was similar to that found in Canadian 11 year olds (Thompson et al., 2003), and based on intervention study findings most likely represent a real difference in physical activity levels (Ernst & Pangrazi, 1999). The sex differences in objectively assessed physical activity followed similar patterns to previous investigations though these studies generally reported higher volumes of activity and greater relative differences between boys and girls than found in our sample (Ekelund et al., 2004; Ness et al., 2007; Van Sluijs et al., 2008). This variation in physical activity between studies is likely due to the use of different ActiGraph count cutpoints and seasonal variability in activity levels.

When ActiGraph data were adjusted to account for the effect of maturity status the significant sex differences in counts • min^{-1}, MPA, VPA, and MVPA disappeared and the effect sizes decreased on average by 54%. These findings are supported by Sherar and colleagues who found that boys and girls who were -4.0 to -1.0 years from APHV spent similar amounts of time in VPA and MVPA (Sherar et al., 2007). In our study girls' mean predicted APHV was 1.5 years more advanced than boys'. This was anticipated and reinforced the typical timing of girls' maturation in advance of boys (Sherar et al., in press). As a consequence of this earlier biological event girls experience changes in stature, body shape, and composition, as well as the emergence of secondary sex characteristics before boys (Malina et al., 2004). It has been posited that during maturation young people are at increased risk of adopting unhealthful behaviors and experiencing psychosocial problems (Sherar et al., in press). On this basis, as girls mature ahead of boys they are more likely to be less physically active and have reduced psychological well-being (e.g., self-perceptions), compared to boys of the same chronological age (Fairclough & Ridgers, 2010). The reasons for these negative health behaviors and consequences are multidimensional. For example, they could relate to physical activity defined by absolute cut-points for moderate and vigorous intensities being perceived as relatively more strenuous for early maturing girls. This is due to their gains in body size being largely a consequence of increased fat mass (Marinov, Kostianev, & Turnovska, 2002), which is inversely associated with cardiorespiratory fitness (Stratton et al., 2007), and contributes little to energy production during short bursts of intermittent weight bearing activity, that is typical of children's MVPA (Baquet, Stratton, Van Praagh, & Berthoin, 2007). Moreover, for similar reasons advanced maturation in girls is associated with poorer performance in weight bearing or endurance activities (Malina et al., 2004). There is also evidence that as girls start to mature they become more concerned about real and perceived evaluation of their bodies by others, which are related to body changes such as increased adiposity (Niven, Fawkner, Knowles, Henretty, & Stephenson, 2009), and reduced psychological well-being, (Krahnstoever Davison, Werder, Trost, Baker, & Birch, 2007). Thus, a combination of biological and psychosocial barriers possibly exert an influence on girls' physical activity during maturation (Sherar et al., 2009), which result in sex differences in physical activity being attributed to girls' earlier maturity (Cumming et al., 2008).

The physical changes experienced by boys during maturation relate more to superior physical performance, particularly in relation to activities requiring speed, strength and power (Malina et al., 2004). Despite the fact that these biological changes are conducive to physical activity participation, boys' activity levels have also been shown to decline with advancing biological age (Sherar et al., 2007). The impact of maturity status on boys' physical activity is under-researched relative to the number of studies focused on girls and so it is not clear why boys' physical activity is also attenuated. It has though been postulated that maturity-related reductions in boys' activity may be due to increased psychological problems (Petersen & Crockett, 1985) and participation in unhealthy behaviours, such as smoking (Simon, Wardle, Jarvis, Steggles, & Cartwright, 2003).

In contrast to the ActiGraph data, significant sex differences in PAQ-C scores remained and indeed were exacerbated when the effect of maturity status was controlled. Specifically, adjusted PAQ-C scores increased for boys and decreased for girls when years from APHV were co-varied into the analysis, resulting in a 23% increase in the effect size. These results are supported by the longitudinal findings of Thompson et al. who observed significant sex differences in PAQ-C scores between 10 year old boys and girls compared by biological age (Thompson et al., 2003). Thompson and associates reported that boys were more active than girls from -4.0 years from APHV with sex differences in PAQ-C scores only disappearing from the APHV onwards (i.e., 0.0 years from APHV) (Thompson et al., 2003). In our sample the biological ages ranged from -4.2 to -1.2 years from APHV (90^{th} percentile = -2.2 years from APHV) for boys compared to -2.4 to -0.2 years from APHV (90^{th} percentile = -0.7 years from APHV) for girls. This lack of alignment between boys' and girls' biological ages may partly explain the negligible influence of maturity status on the PAQ-C comparisons. Additionally, there may have been some over-reporting of physical activity in comparison to objectively assessed physical activity derived from accelerometry (Klesges et al., 2004). Girls at risk of overweight have been reported to overestimate their self-reported physical activity due to social desirability issues, when normal weight girls did not (McMurray et al., 2008). The proportion of boys (25.6%) and girls (21.6%) classified as overweight (Cole, Bellizzi, Flegal, & Dietz, 2000) in our study were similar, but as 50% of girls were within 1.3 years of APHV it is plausible that they experienced somatic changes associated with early maturation, such as increased fat mass. If this was the case an increase in adiposity could be associated with negative self-perceptions particularly in regard to feelings of body attractiveness (Niven et al., 2007), resulting in over-reporting of physical activity for the same social desirability reasons previously observed in overweight girls (McMurray et al., 2008). Support for this tentative supposition is provided by the fact that girls' PAQ-C scores decreased when maturity effects were controlled. However, in order to avoid the known limitations of BMI as a measure of body composition, and to provide a more accurate picture of the effect of adiposity on physical activity and self-perceptions it would be desirable for future studies to include assessment of body fat or body fat distribution, rather than BMI alone.

Strengths of the study were that a non-invasive and objective method was used to estimate maturity status, and established and validated measures of physical activity were utilized to assess the separate influence of maturity status on different physical activity dimensions. There were also limitations to the study. The cross sectional design precluded claims of causality between maturity status and sex differences in physical activity. Moreover, the design only allowed for an estimation of years from APHV, whereas a longitudinal design would have given a more precise assessment of biological age (Thompson et al., 2003). Furthermore, the relationship between maturity and physical activity is influenced by choice of maturity indicator. Years from APHV is a measure of somatic maturity which among girls may be less closely related to physical activity engagement than appearance of secondary sex characteristics (Sherar et al., in press). Though the children were chosen using cluster random sampling they represented only a proportion of 10-11 year olds in one English town and for these reasons the findings may not be easily generalised to other locations.

CONCLUSION

When assessed by chronological age boys were observed to be significantly more active than girls as assessed by self-report and objective physical activity measures. When the analysis controlled for maturity status sex differences in objectively assessed physical activity disappeared, but increased for self-reported physical activity. The detected relationship between maturity status and late primary school children's physical activity may be dependent on physical activity assessment tool employed, reflecting the different aspects of physical activity captured by the respective measures.

Where possible researchers should incorporate maturity status into the design of youth physical activity studies so data analyses can take maturation into account.

ACKNOWLEDGEMENTS

The authors are grateful to Dr Lauren Sherar for her helpful comments on an earlier version of this manuscript. The authors wish to thank all the students and teachers who participating in the project. Gratitude is also expressed to Helen Roberts for coordinating the schools, and to Gareth Harrison, Kate Northcott, Kate McDonnell, Laura Holding, Lucy Page, Will Walker, and Hannah Riley for assisting with the data collection.

REFERENCES

Andersen, L. B., Haaro, M., Sardinha, L. B., Froberg, K., Ekelund, U., Brage, S., et al. (2006). Physical activity and clustered cardiovascular risk in children: A cross-sectional study (The European Youth Heart Study). ***Lancet,*** 368, 299-304.

Baquet, G., Stratton, G., Van Praagh, E., & Berthoin, S. (2007). Improving physical activity assessment in prepubertal childen with high-frequency accelerometry monitoring: A methodological issue. ***Preventive Medicine,*** 44, 143-147.

Baxter-Jones, A., Eisenman, J., & Sherar, L. (2005). Controlling for maturation in pediatric exercise science. ***Pediatric Exercise Science,*** 17, 18-30.

Catellier, D. J., Hannan, P. J., Murray, D. M., Addy, C. L., Conway, T. L., Yang, S., et al. (2006). Imputation of missing data when measuring physical activity by accelerometry. ***Medicine and Science in Sports and Exercise,*** 37, S555-S562.

Census.ac.uk. (2008). ***National Statistics Postcode Directory.*** Retrieved 15th January, 2009, from http://census.ac.uk/guides/Lookup_tables.aspx

Cole, T. J., Bellizzi, M. C., Flegal, K. M., & Dietz, W. H. (2000). Establishing a standard definition for child overweight and obesity worldwide: international survey. ***British Medical Journal,*** 320, 1240-1244.

Crocker, P. R. E., Bailey, D. A., Faulkner, R. A., Kowalski, K. C., & McGraith, R. (1997). Measuring general levels of physical activity: preliminary evidence for the Physical Activity Questionnaire for Older Children. ***Medicine and Science in Sports and Exercise,*** 29, 1344-1349.

Cumming, S. P., Eisenmann, J. C., Smoll, F. L., Smith, R. E., & Malina, R. M. (2006). Body size and perceptions of coaching behaviors in female adolescent athletes. ***Psychology of Sport and Exercise,*** 6, 693-705.

Cumming, S. P., & Riddoch, C. (2009). Physical activity, fitness and children's health: current concepts. In N. Armstrong & W. van Mechelen (Eds.), ***Paediatric***

Exercise Science and Medicine (pp. 327-338). Oxford: Oxford University Press.

Cumming, S. P., Standage, M., Gillison, F., & Malina, R. M. (2008). Sex differences in exercise behaviour during adolescence. Is biological maturation a confounding factor? ***Journal of Adolescent Health,*** 42, 480-485.

Department for Communities and Local Government. (2008). ***The English Indices of Deprivation 2007.*** Wetherby: Communities and Local Government Publications.

Drenowatz, C., Eisenmann, J. C., Pfeiffer, K. A., Wickel, E. E., Gentile, D. A., & Walsh, D. A. (2009). Maturity related differences in physical activity among 10 to 12 year old girls. ***American Journal of Human Biology,*** DOI 10.1002/ajhb.20905 (pre print version).

Eaton, W. O., & Piklai Yu, A. (1989). Are sex differences in child motor activity level a function of sex differences in maturational status? ***Child Development,*** 60, 1005-1011.

Eisenmann, J. C., & Wickel, E. E. (2009). The biological basis of physical activity in children: revisited. ***Pediatric Exercise Science,*** 21, 257-272.

Ekelund, U., Anderssen, S. A., Froberg, K., Sardinha, L. B., Andersen, L. B., & Brage, S. (2007). Independent associations of physical activity and cardiorespiratory fitness with metabolic risk factors in children: the European Youth Heart Study. ***Diabetologia,*** 50, 1832-1840.

Ekelund, U., Sardinha, L. B., Anderssen, S. A., Harro, M., Franks, P. W., Cooper, A. L., et al. (2004). Associations between objectively assessed physical activity and indicators of body fatness in 9 to 10 year old European children: A population-based study from 4 distinct regions in Europe (The European Youth Heart Study). ***American Journal of Clinical Nutrition,*** 80, 584-590.

Ernst, M. P., & Pangrazi, R. P. (1999). Effects of a physical activity program on children's activity levels and attraction to physical activity. ***Pediatric Exercise Science,*** 11, 393-405.

Fairclough, S. J., & Ridgers, N. D. (2010). Relationships between maturity status, physical activity, and physical self-perceptions in primary school children. ***Journal of Sports Sciences,*** 28, 1-9.

Hedges, L. (1981). Distribution theory of Glass's estimator of effect size and related estimators. ***Journal of Educational Statistics,*** 6, 107-128.

Klesges, L. M., Baranowski, T., Beech, B., Cullen, K., Murray, D. M., Rochon, J., et al. (2004). Social desirability bias in self-reported dietary, physical activity and weight concerns measures in 8- to 10-year-old African-American girls: results from the Girls Health Enrichment Multisite Studies (GEMS). ***Preventive Medicine,*** 38, S78-87.

Krahnstoever Davison, K., Werder, J. L., Trost, S. G., Baker, B. l., & Birch, L. L. (2007). Why are early maturing girls less active? Links between pubertal development, psychological well-being, and physical activity among girls at ages 11 and 13. ***Social Science and Medicine,*** 64, 2391-2404.

Lohman, T. G., Roche, A. F., & Martorell, R. (1988). ***Anthropometric Standardization Reference Manual*****.** Champaign, Illinois: Human Kinetics.

Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). ***Growth, Maturation and Physical Activity*****.** Champaign, IL: Human Kinetics.

Marinov, B., Kostianev, S., & Turnovska, T. (2002). Ventilatory efficiency and rate of perceived exertion in obese and non-obese children performing standardized exercise. ***Clinical Physiology and Functional Imaging,*** 22, 254-260.

Mattocks, C., Ness, A. R., Leary, S. D., Tilling, K., Blair, S. N., Sheild, J., et al. (2008). Use of accelerometers in a large field-based study of children:

Protocols, design issues, and effects on precision. ***Journal of Physical Activity and Health,*** 5, S98-S111.

McMurray, R. G., Ward, D. S., Elder, J. P., Lytle, L. A., Strikmiller, P. K., Baggett, C. D., et al. (2008). Do overweight girls overreport physical activity? ***American Journal of Health Behavior,*** 32, 538-546.

Mirwald, R. L., Baxter-Jones, A. D. G., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. ***Medicine and Science in Sports and Exercise,*** 34, 689-694.

Ness, A. R., Leary, S. D., Mattocks, C., Blair, S. N., Reilly, J. J., Wells, J., et al. (2007). Objectively measured physical activity and fat mass in a large cohort of children. ***PLoS Medicine,*** 4(3), e97. doi:10.1371/journal.pmed.0040097.

National Institute for Health and Clinical Excellence. (2009). ***Promoting Physical Activity for Children and Young People*****.** London: NICE.

Niven, A. G., Fawkner, S. G., Knowles, A. M., Henretty, J., & Stephenson, C. (2009). Social physique anxiety and physical activity in early adolescent girls: The influence of maturation and physical activity motives. ***Journal of Sports Sciences,*** 27, 299-305.

Niven, A. G., Fawkner, S. G., Knowles, A. M., & Stephenson, C. (2007). Maturational differences in physical self-perceptions and relationships with physical activity in early adolescent girls. ***Pediatric Exercise Science,*** 19, 472-480.

Petersen, A. C., & Crockett, L. (1985). Pubertal timing and grade effects on adjustment. ***Journal of Youth and Adolescence,*** 14, 191-206.

Petersen, A. C., & Taylor, B. (1980). The biological approach to adolescence: Biological change and psychosocial adaptation. In J. Adelson (Ed.),

Handbook of Adolescent Psychology (pp. 1117-1155). New York: Wiley-Interscience.

Riddoch, C. J., Mattocks, C., Deere, K., Saunders, J., Kirkby, J., Tilling, K., et al. (2007). Objective measurement of levels and patterns of physical activity. ***Archives of Disease in Childhood,*** 92, 963-969.

Sherar, L. B., Cumming, S. P., Eisenmann, J. C., Baxter-Jones, A. D. G., & Malina, R. M. (in press). Adolescent biological maturity and physical activity: Biology meets behaviour. ***Pediatric Exercise Science***.

Sherar, L. B., Esliger, D. W., Baxter-Jones, A. D. G., & Trembaly, M. S. (2007). Age and gender differences in youth physical activity: Does physical maturity matter? ***Medicine and Science in Sports and Exercise,*** 39, 830-835.

Sherar, L. B., Gyurcsik, N. C., Humbert, M. L., Dyck, R. F., Fowler-Kerry, S., & Baxter-Jones, A. D. G. (2009). Activity and barriers in girls (8-16 yr) based on grade and maturity status. ***Medicine and Science in Sports and Exercise,*** 41, 87-95.

Simon, A. E., Wardle, J., Jarvis, M. J., Steggles, N., & Cartwright, M. (2003). Examining the relationship between pubertal stage, adolescent health behaviours and stress. ***Psychological Medicine***, 33, 1369-1379.

Sproston, K., & Primatesta, P. (Eds.). (2003). ***Health Survey for England 2002: The Health of Children and Young People*.** London: The Stationary Office.

Stratton, G., Canoy, D., Boddy, L. M., Taylor, S. R., Hackett, A. F., & Buchan, I. E. (2007). Cardiorespiratory fitness and body mass index of 9-11-year-old English children: a serial cross-sectional study from 1998 to 2004. ***International Journal of Obesity,*** 31, 1172-1178.

Thompson, A. M., Baxter-Jones, A. D. G., Mirwald, R. L., & Bailey, D. A. (2003). Comparison of physical activity in male and female children: does maturation matter? ***Medicine and Science in Sports and Exercise,*** 35, 1684-1690.

Trost, S. G., Pate, R. R., Sallis, J. F., Freedson, P. S., Taylor, W. C., Dowda, M., et al. (2002). Age and gender differences in objectively measured physical activity in youth. ***Medicine and Science in Sports and Exercise,*** 34, 350-355.

Trost, S. G., Ward, D. S., Moorehead, S. M., Watson, P. D., Riner, W., & Burke, J. R. (1998). Validity of the Computer Science and Application (CSA) activity monitor in children. ***Medicine and Science in Sports and Exercise,*** 30, 629-633.

Van Sluijs, E. M. F., Skidmore, P. M. L., Mwanza, K., Jones, A. P., Callaghan, A. M., Ekelund, U., et al. (2008). Physical activity and dietary behaviour in a population-based sample of British 10 year old children: The SPEEDY study (Sport, Physical activity and Eating behaviour: Environmental Determinants in Young people). ***BMC Public Health,*** 8(388), doi:10.1186/1471-2458-1188-1388.

Wickel, E. E., Eisenmann, J. C., & Welk, G. J. (2009). Maturity-related variation in moderate-to-vigorous physical activity among 9-14 year olds. ***Journal of Physical Activity and Health,*** 6, 597-605.Andersen, L. B., Haaro, M., Sardinha, L. B., Froberg, K., Ekelund, U., Brage, S., & Anderssen, S. A. (2006). Physical activity and clustered cardiovascular risk in children: A cross-sectional study (The European Youth Heart Study). *Lancet, 368*, 299-304.

Baquet, G., Stratton, G., Van Praagh, E., & Berthoin, S. (2007). Improving physical activity assessment in prepubertal childen with high-frequency accelerometry monitoring: A methodological issue. *Preventive Medicine, 44*, 143-147.

Baxter-Jones, A., Eisenman, J., & Sherar, L. (2005). Controlling for maturation in pediatric exercise science. *Pediatric Exercise Science, 17*, 18-30.

Catellier, D. J., Hannan, P. J., Murray, D. M., Addy, C. L., Conway, T. L., Yang, S., & Rice, J. C. (2006). Imputation of missing data when measuring physical activity by accelerometry. *Medicine and Science in Sports and Exercise, 37*(11 (Suppl)), S555-S562.

Census.ac.uk. (2008). National Statistics Postcode Directory. Retrieved 15th January, 2009, from http://census.ac.uk/guides/Lookup_tables.aspx

Cole, T. J., Bellizzi, M. C., Flegal, K. M., & Dietz, W. H. (2000). Establishing a standard definition for child overweight and obesity worldwide: international survey. *British Medical Journal, 320*, 1240-1244.

Crocker, P. R. E., Bailey, D. A., Faulkner, R. A., Kowalski, K. C., & McGraith, R. (1997). Measuring general levels of physical activity: preliminary evidence for the Physical Activity Questionnaire for Older Children. *Medicine and Science in Sports and Exercise, 29*(10), 1344-1349.
Cumming, S. P., Eisenmann, J. C., Smoll, F. L., Smith, R. E., & Malina, R. M. (2006). Body size and perceptions of coaching behaviors in female adolescent athletes. *Psychology of Sport and Exercise, 6*, 693-705.
Cumming, S. P., & Riddoch, C. (2009). Physical activity, fitness and children's health: current concepts. In N. Armstrong & W. van Mechelen (Eds.), *Paediatric Exercise Science and Medicine* (pp. 327-338). Oxford: Oxford University Press.
Cumming, S. P., Standage, M., Gillison, F., & Malina, R. M. (2008). Sex differences in exercise behaviour during adolescence. Is biological maturation a confounding factor? *Journal of Adolescent Health, 42*, 480-485.
DepartmentforCommunitiesandLocalGovernment. (2008). *The English Indices of Deprivation 2007*. Wetherby: Communities and Local Government Publications.
Drenowatz, C., Eisenmann, J. C., Pfeiffer, K. A., Wickel, E. E., Gentile, D. A., & Walsh, D. A. (2009). Maturity related differences in physical activity among 10 to 12 year old girls. *American Journal of Human Biology, DOI 10.1002/ajhb.20905*(pre print version).
Eaton, W. O., & Piklai Yu, A. (1989). Are sex differences in child motor activity level a function of sex differences in maturatioanl status? *Child Development, 60*, 1005-1011.
Eisenmann, J. C., & Wickel, E. E. (2009). The biological basis of physical activity in children: revisited. *Pediatric Exercise Science, 21*, 257-272.
Ekelund, U., Anderssen, S. A., Froberg, K., Sardinha, L. B., Andersen, L. B., & Brage, S. (2007). Independent associations of physical activity and cardiorespiratory fitness with metabolic risk factors in children: the European Youth Heart Study. *Diabetologia, 50*, 1832-1840.
Ekelund, U., Sardinha, L. B., Anderssen, S. A., Harro, M., Franks, P. W., Cooper, A. L., . . . Froberg, K. (2004). Associations between objectively assessed physical activity and indicators of body fatness in 9 to 10 year old European children: A population-based study from 4 distinct regions in Europe (The European Youth Heart Study). *American Journal of Clinical Nutrition, 80*, 584-590.
Ernst, M. P., & Pangrazi, R. P. (1999). Effects of a physical activity program on children's activity levels and attraction to physical activity. *Pediatric Exercise Science, 11*(4), 393-405.
Fairclough, S. J., & Ridgers, N. D. (2010). Relationships between maturity status, physical activity, and physical self-perceptions in primary school children. *J Sports Sci, 28*(1), 1-9. doi: 917699179 [pii]
10.1080/02640410903334780
Hedges, L. (1981). Distribution theory of Glass's estimator of effect size and related estimators. *Journal of Educational Statistics, 6*, 107-128.
Klesges, L. M., Baranowski, T., Beech, B., Cullen, K., Murray, D. M., Rochon, J., & Pratt, C. (2004). Social desirability bias in self-reported dietary, physical activity and weight concerns measures in 8- to 10-year-old African-American girls: results from the Girls Health Enrichment Multisite Studies (GEMS). *Prev Med, 38 Suppl*, S78-87. doi: 10.1016/j.ypmed.2003.07.003
S0091743504000519 [pii]
Krahnstoever Davison, K., Werder, J. L., Trost, S. G., Baker, B. l., & Birch, L. L. (2007). Why are early maturing girls less active? Links between pubertal

development, psychological well-being, and physical activity among girls at ages 11 and 13. *Social Science and Medicine, 64*(12), 2391-2404.
Lohman, T. G., Roche, A. F., & Martorell, R. (1988). *Anthropometric Standardization Reference Manual*. Champaign, Illinois: Human Kinetics.
Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, Maturation and Physical Activity*. Champaign, IL: Human Kinetics.
Marinov, B., Kostianev, S., & Turnovska, T. (2002). Ventilatory efficiency and rate of perceived exertion in obese and non-obese children performing standardized exercise. *Clinical Physiology and Functional Imaging, 22*(4), 254-260.
Mattocks, C., Ness, A. R., Leary, S. D., Tilling, K., Blair, S. N., Sheild, J., . . . Riddoch, C. H. (2008). Use of accelerometers in a large field-based study of children: Protocols, design issues, and effects on precision. *Journal of Physical Activity and Health, 5*(Supp. 1), S98-S111.
McMurray, R. G., Ward, D. S., Elder, J. P., Lytle, L. A., Strikmiller, P. K., Baggett, C. D., & Young, D. R. (2008). Do overweight girls overreport physical activity? *Am J Health Behav, 32*(5), 538-546. doi: 10.5555/ajhb.2008.32.5.538
Mirwald, R. L., Baxter-Jones, A. D. G., Bailey, D. A., & Beunen, G. P. (2002). An assessment of maturity from anthropometric measurements. *Medicine and Science in Sports and Exercise, 34*(4), 689-694.
Ness, A. R., Leary, S. D., Mattocks, C., Blair, S. N., Reilly, J. J., Wells, J., . . . Riddoch, C. J. (2007). Objectively measured physical activity and fat mass in a large cohort of children. *PLoS Medicine, 4*(3), e97. doi:10.1371/journal.pmed.0040097.
NICE. (2009). *Promoting Physical Activity for Children and Young People*. London: NICE.
Niven, A. G., Fawkner, S. G., Knowles, A. M., Henretty, J., & Stephenson, C. (2009). Social physique anxiety and physical activity in early adolescent girls: The influence of maturation and physical activity motives. *Journal of Sports Sciences, 27*(3), 299-305.
Niven, A. G., Fawkner, S. G., Knowles, A. M., & Stephenson, C. (2007). Maturational differences in physical self-perceptions and relationships with physical activity in early adolescent girls. *Pediatric Exercise Science, 19*, 472-480.
Petersen, A. C., & Crockett, L. (1985). Pubertal timing and grade effects on adjustment. *Journal of Youth and Adolescence, 14*, 191-206.
Petersen, A. C., & Taylor, B. (1980). The biological approach to adolescence: Biological change and psychosocial adaptation. In J. Adelson (Ed.), *Handbook of Adolescent Psychology* (pp. 1117-1155). New York: Wiley-Interscience.
Riddoch, C. J., Mattocks, C., Deere, K., Saunders, J., Kirkby, J., Tilling, K., . . . Ness, A. R. (2007). Objective measurement of levels and patterns of physical activity. *Archives of Disease in Childhood, 92*, 963-969.
Sherar, L. B., Cumming, S. P., Eisenmann, J. C., Baxter-Jones, A. D. G., & Malina, R. M. (in press). Adolescent biological maturity and physical activity: Biology meets behaviour. *Pediatric Exercise Science, doi unknown*.
Sherar, L. B., Esliger, D. W., Baxter-Jones, A. D. G., & Trembaly, M. S. (2007). Age and gender differences in youth physical activity: Does physical maturity matter? *Medicine and Science in Sports and Exercise, 39*, 830-835.
Sherar, L. B., Gyurcsik, N. C., Humbert, M. L., Dyck, R. F., Fowler-Kerry, S., & Baxter-Jones, A. D. G. (2009). Activity and barriers in girls (8-16 yr) based on grade and maturity status. *Medicine and Science in Sports and Exercise, 41*(1), 87-95.

Simon, A. E., Wardle, J., Jarvis, M. J., Steggles, N., & Cartwright, M. (2003). Examining the relationship between pubertal stage, adolescent health behaviours and stress. *Psychol Med*, *33*(8), 1369-1379.

Sproston, K., & Primatesta, P. (Eds.). (2003). *Health Survey for England 2002: The Health of Children and Young People*. London: The Stationary Office.

Stratton, G., Canoy, D., Boddy, L. M., Taylor, S. R., Hackett, A. F., & Buchan, I. E. (2007). Cardiorespiratory fitness and body mass index of 9-11-year-old English children: a serial cross-sectional study from 1998 to 2004. *International Journal of Obesity*, *31*, 1172-1178.

Thompson, A. M., Baxter-Jones, A. D. G., Mirwald, R. L., & Bailey, D. A. (2003). Comparison of physical activity in male and female children: does maturation matter? *Medicine and Science in Sports and Exercise*, *35*(10), 1684-1690.

Trost, S. G., Pate, R. R., Sallis, J. F., Freedson, P. S., Taylor, W. C., Dowda, M., & Sirard, J. (2002). Age and gender differences in objectively measured physical activity in youth. *Medicine and Science in Sports and Exercise, 34*(2), 350-355.

Trost, S. G., Ward, D. S., Moorehead, S. M., Watson, P. D., Riner, W., & Burke, J. R. (1998). Validity of the Computer Science and Application (CSA) activity monitor in children. *Medicine and Science in Sports and Exercise*, *30*(4), 629-633.

Van Sluijs, E. M. F., Skidmore, P. M. L., Mwanza, K., Jones, A. P., Callaghan, A. M., Ekelund, U., . . . Griffin, S. J. (2008). Physical activity and dietary behaviour in a population-based sample of British 10 year old children: The SPEEDY study (Sport, Physical activity and Eating behaviour: Environmental Determinants in Young people). *BMC Public Health*, *8*(388), doi:10.1186/1471-2458-1188-1388.

Wickel, E. E., Eisenmann, J. C., & Welk, G. J. (2009). Maturity-related variation in moderate-to-vigorous physical activity among 9-14 year olds. *Journal of Physical Activity and Health, 6*, 597-605.