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To link to this article: http://dx.doi.org/10.3109/14767058.2015.1049525

Published online: 02 Jul 2015.

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ORIGINAL ARTICLE

Maternal physical activity before and during the prenatal period and the offspring’s academic performance in youth. The UP&DOWN study

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Abstract

Objective: To examine the association of maternal physical activity before and during pregnancy with academic performance in youth.

Methods: This study included 1868 youth (6–18 years) and their mothers. Mothers recalled their physical activity before and during pregnancy. Mothers were categorized into four groups: “remained active”, “became inactive”, “became active” and “remained inactive”. Academic performance was assessed through school records.

Results: Boys whose mothers practiced physical activity before or during pregnancy had significantly higher scores in academic performance indicators independently of physical activity, fitness, current body mass index (BMI) and birthweight than those whose mothers did not practice physical activity before or during pregnancy (all p < 0.05). In addition, boys whose mothers remained active had higher scores in all academic indicators (ranging from +0.358 to +0.543) than boys whose mothers remained inactive. Boys whose mothers remained active had higher scores in Language (score +0.546; 95% CI, 0.150–0.940), average of Math and Language (score +0.468; 95% CI, 0.100–0.836) and grade point average (GPA) (score +0.368; 95% CI, 0.092–0.644) than boys whose mothers became active.

Conclusions: Maternal physical activity before and during pregnancy may positively influence youth’s academic performance. Continuing maternal physical activity practice during pregnancy may have greater benefits for youth’s academic performance.

Introduction

There is increasing evidence that prenatal environment influences fetal development and may have implications for the offspring’s health later in life [1–3]. Medical and scientific groups, such as the American College of Obstetrics and Gynecology, the US Department of Health and Human Services and the American College of Sports Medicine, recommend that pregnant women should engage in regular physical activity [4–6]. A growing body of evidence suggests that maternal prenatal physical activity has both short-term benefits (i.e. effect on fetal cardiac programming by reducing fetal heart rate and increasing heart rate variability, lower risk of developing oligohydramnios, increased endothelium-dependent vasodilation) and longer-term benefits (i.e. lower birthweights, lower risk of large size for gestational age) on the offspring [7–10]. Little is known, however, about the effects of maternal physical activity during this period on the offspring’s cognitive development [11].

Several animal studies support an association between maternal physical activity in pregnant mice and improved learning and memory in the offspring [12–16]. In humans,
only a few studies have examined the association between maternal physical activity during pregnancy and the offspring’s cognitive functioning. Three studies by Clapp and colleagues used small sample sizes (n < 105) and focused on the first years of life (<6 years); thereby long-term effects cannot be elucidated [17–19]. Another study found contradictory evidence regarding the offspring’s cognitive benefits at different stages of age: maternal physical activity was positively associated with the offspring’s verbal ability at 15 months of age, not associated at 38 months and negatively associated with verbal intelligence quotient at age 8 years [20]. Additionally, none of these studies took into account the independent effect of pre-pregnancy physical activity. Interestingly, maternal physical activity before pregnancy might facilitate physical activity during pregnancy and prepare mothers for a healthy pregnancy [21]. In addition, as women usually do not realize they are pregnant for the first few weeks, when essential fetal processes have already started, physical activity begun during pregnancy may miss the periconceptional period [22]. Therefore, practicing physical activity before pregnancy may be at least as important as during pregnancy. To the best of our knowledge, there is no study investigating the association between prenatal physical activity of women and youth academic performance. The present study examined the association of maternal physical activity before and during pregnancy with academic performance in youth aged 6–18 years.

Materials and methods

Participants

This research was based on data from the UP&DOWN study [23]. In brief, the UP&DOWN study is a 3-year longitudinal study designed to assesses the impact over time of physical activity and sedentary behaviors on health indicators in a Spanish sample of children and adolescents. Data were collected from September 2011 to June 2012. Participants’ selection criteria for healthy children and adolescents were (i) to study in 1st/4th grades for children, and 7th/10th grades for adolescents at baseline and (ii) do not have physical disability or health problems, which might limit levels of physical activity. Children and adolescents were recruited from schools in Cadiz and Madrid, respectively. A total of 2225 youth aged 6–18 years participated in the UP&DOWN study. The present analyses included 1868 youth (921 girls; 84% of the original sample) with complete data at baseline on mother’s physical activity and child’s academic performance.

Parents and school supervisors were informed by letter about the nature and purpose of the study, and written informed consent was provided. The study protocols were approved by the Ethics Committee of the Hospital Puerta de Hierro (Madrid, Spain) and the Bioethics Committee of the National Research Council (Madrid, Spain).

Maternal physical activity before and during pregnancy

Mothers were asked to recall their physical activity before and during pregnancy. Mothers answered the following questions: “Do you practice physical activity before pregnancy?”, and “Do you practice physical activity during pregnancy?”. The possible answers were yes or no.

Youth academic performance

Academic performance was assessed through grades reported on the transcript at the end of the academic year. Academic performance was based on four indicators: Math, Language, an average of these two core subjects and grade point average (GPA) score. GPA score was standardized by calculating a single average for the examinable subjects in each grade [24]. We used Math and Language as individual indicators due to the important role of cognitive control (i.e. inhibition and working memory) plays in these areas [25]. Other previous studies have also used these indicators to assess academic performance [26–28]. For analytic purposes, individual letter grades were converted to numeric data as follows: A = 5, B = 4, C = 3, D = 2 and F = 1.

Covariates

Participants’ age, sex, city (Cadiz/Madrid) and maternal education level (below university education and university education) were recorded [29]. Gestational age at time of delivery (weeks) and birthweight (kg) were reported by parents.

Anthropometric measurements and fitness in participants were assessed following the ALPHA health-related fitness test battery for youth [30]. Body mass index (BMI) was calculated as kg/m². Cardiorespiratory fitness was assessed by the 20-m shuttle-run test and motor fitness was assessed with the 4 × 10-m shuttle-run test of speed-of-movement, agility and coordination [30]. A single physical fitness score was calculated as the mean of the two z-standardized scores [26].

Youth’s physical activity was measured by accelerometry [31]. The physical activity variable included in this study was counts per minute and was included as a measure of total physical activity.

Statistical analysis

The characteristics of participants and outcomes are presented as means (SD) or percentages. Differences between sexes were determined by one-way analysis of variance and Chi-squared tests for continuous and nominal variables, respectively. Since significant interactions were found between sex and maternal physical activity in relation to outcomes, all analyses were performed separately for boys and girls.

The association of maternal physical activity before pregnancy (yes/no) with youth’s academic performance was analyzed by one-way analysis of covariance (ANCOVA) with Bonferroni adjustment using three separate models: model 1 was controlled for age, city and maternal education; model 2 was additionally controlled for birthweight and gestational age and model 3 was further adjusted for the current levels of BMI, physical activity and physical fitness. We also conducted ANCOVA to examine the association of maternal physical activity during pregnancy (yes/no) with youth’s academic performance, using the three previous models.
The association of changes in maternal physical activity practice from before (yes/no) to during (yes/no) pregnancy with youth’s academic performance was analyzed by ANCOVA, using the same previous models. Youth were categorized into four groups according to the physical activity practices of their mothers from before to during pregnancy: ‘remained active’, ‘became inactive’, ‘became active’ and ‘remained inactive’. Analyses were performed with the IBM SPSS Statistics 18.0 for Windows (IBM Co., Armonk, NY) and the level of significance was set to 0.05.

Results

Table 1 shows the descriptive characteristics of the study sample.

Table 2 shows the association of maternal physical activity before pregnancy and during pregnancy with youth’s academic performance. For maternal physical activity before pregnancy, across the three models, boys whose mothers practiced physical activity before pregnancy had significantly higher scores in all academic performance indicators than those whose mothers did not practice physical activity before pregnancy (all \( p \leq 0.002 \)). For maternal physical activity during pregnancy, boys whose mothers practiced physical activity during pregnancy had significantly higher scores in three of the four academic indicators than those whose mothers were not active, across the three models (all \( p < 0.05 \)). For Math score, the association was attenuated in models 2 and 3 (\( p < 0.10 \)).

Table 3 shows the association of maternal physical activity changes from before to during pregnancy with youth academic performance. Among boys, significant differences in all academic performance variables were found across the groups (\( p < 0.05 \)). Boys whose mothers remained active had higher scores in Math (score +0.420; 95% CI, 0.160–0.680), Language (score +0.543; 95% CI, 0.280–0.810) average of Math and Language (score +0.481; 95% CI, 0.232–0.731) and GPA (score +0.358; 95% CI, 0.171–0.546) than boys whose mothers remained inactive. Boys whose mothers remained active had higher scores in Language (score +0.546; 95% CI, 0.150–0.940), average of Math and Language (score +0.468; 95% CI, 0.100–0.836) and GPA (score +0.368; 95% CI, 0.092–0.644) than boys whose mothers became active.

Discussion

A main finding of the present study was that maternal physical activity before and during pregnancy was related to youth’s academic performance in boys, but not in girls. In addition, boys whose mothers were active before and during pregnancy had higher academic performance than those whose mothers continued being inactive or became active. Importantly, these findings were independent of potential confounders, specifically physical activity, fitness, current BMI and birthweight, which might modify the aforementioned associations due to their relationship with both outcomes and exposures [3,32]. These novel results expand the previous evidence on the benefits of maternal prenatal physical activity on the offspring’s health, indicating that an active lifestyle before and during the prenatal period may have a beneficial influence on youth academic performance in boys.

One of the novel aspects in this study was to take into account the independent effect of maternal physical activity before pregnancy on youth’s academic performance. We found that boys whose mothers were active before pregnancy had higher scores in all academic indicators than those whose mothers were not active before pregnancy. These encouraging

Table 1. Descriptive characteristics of study sample.

<table>
<thead>
<tr>
<th></th>
<th>All (1868)</th>
<th>Boys (947)</th>
<th>Girls (921)</th>
<th>( P_{\text{for sex}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical characteristics</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (yr)</td>
<td>10.18 ± 3.31</td>
<td>10.10 ± 3.30</td>
<td>10.26 ± 3.31</td>
<td>0.288</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>41.21 ± 15.72</td>
<td>41.77 ± 16.84</td>
<td>40.62 ± 14.46</td>
<td>0.113</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>142.66 ± 18.23</td>
<td>143.40 ± 19.42</td>
<td>141.90 ± 16.90</td>
<td>0.075</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>19.45 ± 3.68</td>
<td>19.42 ± 3.70</td>
<td>19.47 ± 3.66</td>
<td>0.795</td>
</tr>
<tr>
<td>Birth weight (kg)</td>
<td>3.24 ± 0.55</td>
<td>3.30 ± 0.56</td>
<td>3.17 ± 0.54</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Gestational age (wk)</td>
<td>38.79 ± 2.49</td>
<td>38.70 ± 2.39</td>
<td>38.70 ± 2.6</td>
<td>0.966</td>
</tr>
<tr>
<td>Maternal education level university (%)</td>
<td>29</td>
<td>32</td>
<td>25</td>
<td>0.002</td>
</tr>
<tr>
<td>Fitness (z-score)*</td>
<td>0.00 ± 0.93</td>
<td>0.25 ± 1.01</td>
<td>−0.26 ± 0.75</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total PA (cpm)</td>
<td>510.66 ± 141.22</td>
<td>562.37 ± 139.19</td>
<td>457.50 ± 122.43</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Table 2. Association of maternal physical activity before pregnancy and during pregnancy with youth’s academic performance.

Table 3. Association of changes in maternal physical activity from before to during pregnancy with youth’s academic performance.

Values are mean ± SD or percentages; cpm, count per minute; PA, physical activity.

* z-Score computed from the 20-m shuttle-run test and the 4 × 10-m shuttle-run test.

Statistically significant values are shown in bold.
Table 2. Differences in youth academic performance between youth whose mothers practiced physical activity before/during pregnancy and youth whose mother did not practice physical activity before/during pregnancy.

<table>
<thead>
<tr>
<th>Maternal physical activity before pregnancy</th>
<th>Maternal physical activity during pregnancy</th>
<th>Yes versus No</th>
<th>Mean difference</th>
<th>p (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Yes versus No</td>
<td>Yes Mean ± SD</td>
<td>No Mean ± SD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Model 1</td>
<td>519</td>
<td>3.38 ± 1.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Model 2</td>
<td>428</td>
<td>3.38 ± 1.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Model 3</td>
<td>454</td>
<td>3.38 ± 1.36</td>
</tr>
<tr>
<td>Boys (n = 947)</td>
<td>Math (1–5)</td>
<td>3.51 ± 1.26</td>
<td>3.31 ± 1.26</td>
<td>0.20 (0.066, 0.339)</td>
</tr>
<tr>
<td></td>
<td>Language (1–5)</td>
<td>3.51 ± 1.26</td>
<td>3.31 ± 1.26</td>
<td>0.20 (0.066, 0.339)</td>
</tr>
<tr>
<td></td>
<td>Math &amp; Language (1–5)</td>
<td>3.51 ± 1.26</td>
<td>3.31 ± 1.26</td>
<td>0.20 (0.066, 0.339)</td>
</tr>
<tr>
<td></td>
<td>Grade point average (1–5)</td>
<td>3.68 ± 0.87</td>
<td>3.49 ± 0.87</td>
<td>0.19 (0.068, 0.32)</td>
</tr>
</tbody>
</table>

Model 1: Adjustments for maternal age, city residence (Madrid/Cadiz) and maternal education (university level/below university level). Model 2: Adjustments for model 1 plus birth weight (kg) and gestational age (wk). Model 3: Adjustments for model 2 plus physical activity (cpm), body mass index (kg/m²) and fitness (Z-scores). Statistically significant values are shown in bold and borderline significant values are shown in italic.

Recent evidence in animals supports that maternal physical activity during pregnancy may be beneficial for fetal brain development [14,16,38]. Experimental studies in rats showed that physical activity during gestation in pregnant mothers can increase hippocampal BDNF mRNA (brain-derived neurotrophic factor messenger ribonucleic acid) expression in postnatal pups [16] and can improve objective recognition memory in adult male offspring [38]. It has been previously shown that some maternally derived growth factors (e.g. BDNF) cross the placenta and are active in the fetus [39].

Findings may have several explanations. First, women are unaware they are pregnant for the first few weeks, when essential fetal processes have already started. Organogenesis (i.e. the formation and differentiation of organs during embryonic development) extends from the second to the eighth week of gestation. This period is extremely vulnerable, so environmental factors may produce particularly strong influences for embryonic growth, resulting in positive or negative health consequences later in life [22,33]. Maternal stress early in pregnancy may influence hippocampal dependent learning and memory [34] as well as increase the risk of schizophrenia in the offspring males [35].

Regular physical activity practice may provide substantial health benefits for women before pregnancy and reduce the risk for an adverse pregnancy [6], for example, preventing maternal overweight, preeclampsia or gestational diabetes [36,37]. Thus, being physically active before pregnancy might counteract, to some extent, such consequences and generate beneficial eventual effects on youth academic performance. A woman's lifestyle before pregnancy is the strongest predictor of her lifestyle during pregnancy [21]. For example, in the present study, 74% of women who were physically active or inactive before pregnancy maintained their lifestyle during pregnancy. Consequently, women who practice physical activity before pregnancy may be more likely to continue being active during pregnancy, contributing to a greater benefit for youth academic performance later in life.

The present study examined the effect of maternal physical activity during pregnancy on youth's academic performance during childhood and adolescence. Other studies investigated the association between maternal physical activity during pregnancy and the offspring's cognitive functioning in the first years of life. Five days after their birth, the offspring of the mothers who practiced physical activity during pregnancy had higher scores in the orientation and state regulation subscales of the Brazelton Neonatal Behavioral Assessment Scales [19]. Another study found that at the age of 1 year there were not differences in mental ability between the offspring whose mothers were active during pregnancy with those whose mothers were not active [18]. However, in a separate study, the 5-year-old children of the active mothers group performed better on tests of general intelligence and oral language [17]. Thus, the aforementioned findings seems to be inconsistent throughout the first years of life, and the long-term effects of maternal physical activity during pregnancy on the offspring's cognitive functioning has been inadequately studied. In the present study, boys aged 6–18 years whose mothers were active during pregnancy had higher scores in all academic indicators.

Recent evidence in animals supports that maternal physical activity during pregnancy may be beneficial for fetal brain development [14,16,38]. Experimental studies in rats showed that physical activity during gestation in pregnant mothers can increase hippocampal BDNF mRNA (brain-derived neurotrophic factor messenger ribonucleic acid) expression in postnatal pups [16] and can improve objective recognition memory in adult male offspring [38]. It has been previously shown that some maternally derived growth factors (e.g. BDNF) cross the placenta and are active in the fetus [39].
Importantly, BDNF is implicated in brain plasticity, which in turn, may enhance cognitive function [40]. Thus, the offspring’s cognitive and academic performance might be enhanced.

Another interesting finding was that boys whose mothers maintained the physical activity practice during pregnancy scored higher in all academic indicators than those whose mothers continued being inactive or became active. It seems that being physically active just during the pregnancy period could be insufficient to lead to beneficial effects in the offspring’s academic performance. Pregnancy lasts 9 months, a short period in which the effects of maternal physical activity on fetus might not have a benefit if the organism was not previously prepared. Regular physical activity enhances important aspects of the maternal physiologic adaptations to pregnancy in ways that are also fetoprotective [41]. However, although we examined maternal physical activity before and during pregnancy separately, it is difficult to determine the independent biological relevance of the two exposure periods. As mentioned, pre-pregnancy physical activity is one of the strongest correlates of physical activity during pregnancy [21]. In addition, the physical activity recommendation for the general population is similar to that for pregnant women [6]. Thus, it is not clear whether physical activity before pregnancy or during pregnancy contributes to the offspring’s academic performance, or whether both are required.

The reasons explaining why maternal physical activity before and during the prenatal period might improve academic performance only in the offspring boys cannot be elucidated, yet some candidate mechanisms should be explored. Maternal stressors may impact brain development, especially the hippocampus and hypothalamus, and cognitive abilities in the offspring in a sex-dependent manner [42,43]. For example, the effect of maternal stress on placental gene expression in mice was found only in the male offspring; male placenta exhibited increases in the expression of several genes important in growth and development, such as insulin-like growth factor-binding protein 1 (IGFBP-1) [44]. An elevation in placental IGFBP-1 could potentially decrease the available growth factors during critical developmental periods, and plays a role in fetal programming and brain development, which were specific to males [45]. In humans, the influence of maternal depression during pregnancy on offspring postnatal anxiety development was detected only in boys [46]. The majority of evidence was focused on negative stressors; however, the offspring outcomes varied depending upon the stressor involved [47]. As such, physical activity might be a positive stressor for cognitive functioning, as it augments brain plasticity by facilitating adaptive and protective processes through the mediation of BDNF and insulin-like growth factor-1 [48,49].

The present study had several limitations. The fact that it was undertaken in a convenience sample limits its generalizability. The lack of mothers’ cognitive indicators, the use of simple, self-reported measures of maternal physical activity before and during pregnancy and the difficulty to determine the independent biological relevance of the two exposure periods must be acknowledged, so present findings must be interpreted with caution. Strengths of the study included the relatively large and heterogeneous sample of children and adolescents, the objective assessment of physical activity and fitness, and the use of school records to assess academic performance.

In conclusion, the results indicated that maternal physical activity before and during pregnancy was positively associated with youth academic performance in boys. Thus, promoting physical activity among women of reproductive age may improve youth academic performance later in life. Further, longitudinal studies and clinical trials may help to confirm the sex- and time-specific effects of prenatal maternal physical activity on youth’s academic performance.

Acknowledgements

The authors thank youth, parents and teachers who participated in this study.

Declaration of interest

None of the authors had any conflicts of interest.
This study was supported by the DEP 2010-21662-C04-00 grant from the National Plan for Research, Development and Innovation (R+D+i) MICINN.

References