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Original article

The effect of maternal risk factors during pregnancy on children's motor development at 5–6 years

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SUMMARY

Background and aims: Maternal diet and health may influence a child's later neurodevelopment. We investigated the effect of maternal diet, adiposity, gestational diabetes mellitus (GDM), and depressive/anxiety symptoms during pregnancy on the child's motor outcome at 5–6 years.

Methods: The motor performance of 159 children of women with overweight or obesity (pre-pregnancy body mass index 25–29.9 kg/m^2 and ≥30 kg/m^2, respectively) was assessed by the Movement Assessment Battery for Children – Second Edition (Movement ABC-2, total scores and subscales of manual dexterity, aiming and catching, balance) at 5–6 years. Higher percentiles denoted better motor performance with ≤15th percentiles for total scores being used as a cut-off for developmental coordination disorder (DCD). Diet (dietary patterns from three-day food diaries and fish consumption from a frequency questionnaire), adiposity (air displacement plethysmography), depression and anxiety symptoms (Edinburgh Postnatal Depression scale and the SCL-90/anxiety subscale, respectively) were assessed in early and late pregnancy. GDM was diagnosed with an oral glucose tolerance test at early or mid-pregnancy. Logistic and general regression models were used to analyse the associations.

Results: The mean percentiles for total scores of the Movement ABC-2 were 47.5 (SD 28.3), and 14.3 % of the children had DCD. A healthier maternal dietary pattern in early pregnancy associated with better motor performance in the child at 5–6 years (adj.mean difference = 9.80, 95%CI = 0.66–19.0). Higher maternal body fat mass both in early and late pregnancy (adj.OR = 1.07, 95%CI = 1.01–1.13, and adj.OR = 1.08, 95%CI = 1.02–1.14) and fat percentage in late pregnancy (adj.OR = 1.12, 95%CI = 1.09–1.24) were associated with higher odds for DCD. Increasing maternal depressive symptoms were associated with lower odds for impaired aiming/catching (early/late pregnancy adj.OR = 0.78, 95%CI = 0.65–0.93, adj.OR = 0.82, 95%CI = 0.70–0.96). GDM was not associated with the motor performance.

Conclusions: A healthier dietary pattern during pregnancy favoured children's motor development, while it was compromised by higher maternal adiposity. Promoting an overall healthy diet throughout pregnancy might support the motor development in children born to mothers with overweight or obesity.

Abbreviations: EPDS, Edinburgh Postnatal Depression Scale; DCD, Developmental Coordination Disorder; GDM, gestational diabetes mellitus; GW, gestational week; Movement ABC-2, Movement Assessment Battery for Children, Second Edition; OGTT, oral glucose tolerance test; SCL-90, Symptoms Checklist-90/Anxiety subscale.

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Our findings indicating that maternal depressive symptoms during pregnancy might associate with better motor performance in the child will require further research for confirmation.

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1. Introduction

The developmental coordination disorder (DCD) is defined as a motor impairment that interferes with the activities of daily living or academic performance [1]. The most frequently quoted prevalence of DCD is 5–6% in the general population of the children. Male sex and preterm birth are known to increase the risk for DCD [1], which in turn has been linked with lower levels of physical activity [2]. For example, it has been demonstrated that DCD is associated with obesity, internalising symptoms, cognitive difficulties, and a lower quality of life [3–5]. DCD and its comorbidities are known to persist into adulthood representing a considerable burden not only at the individual level but also from the viewpoint of the society [1]. Less consistent findings are available on whether maternal factors during pregnancy can affect motor development [6]. Several factors, such as obesity or nutrition, could affect the foetal programming by disturbing the optimal developmental conditions in the uterus [7].

The prevalence of overweight and obesity (body mass index, BMI 25–29.9 kg/m^2 and BMI $\geq$30 kg/m^2, respectively) has increased globally [8] and Finland is not unaffected, since almost every other pregnant woman has overweight or obesity before pregnancy [9]. The presence of obesity and its comorbidity, gestational diabetes mellitus (GDM), have been linked with poorer language, cognitive and motor skills in children in an age range 1–9 years [10–16]. On the other hand, it should be stated that some other investigators have not detected these associations [12,13,17,18]. Women with obesity may experience more depressive and anxiety symptoms during pregnancy than women with normal weight (BMI<25 kg/m^2) [19,20]. Previous reports have shown that if the mother is depressed and/or anxious during her pregnancy, this may affect her child's later neurodevelopment, including his/her cognitive, motor, language, and socio-emotional skills [21–23]. Once again, divergent findings have been reported [24,25].

Modification of early life circumstances could be an effective way to support later neurodevelopment. Dietary intake is tightly connected to the maternal obesity status and it has been reported that mothers with depressive symptoms tend to have a poorer dietary quality [26]. There is some evidence that a good dietary quality or a healthy dietary pattern, typically including vegetables, fruits, whole-grains and fish, during pregnancy could improve a child's language, motor, and cognitive skills [27–29] while an unhealthy diet may have unfavourable effects [30,31].

It is not known if there are putative associations between early life factors and motor development in the population of children born to mothers with overweight or obesity; these children represent a risk-group for adverse long-term neurodevelopment. Our aim was to investigate the prevalence of DCD and whether maternal 1) diet (dietary patterns and fish consumption), 2) GDM and adiposity (pre-pregnancy BMI and body composition), and 3) depressive and anxiety symptoms during pregnancy would associate with motor performance of the children at the age of 5–6 years.

2. Material and methods

2.1. Study participants and design

The data for this study originate from a double-blind, placebo-controlled randomised trial (ClinicalTrials.gov Identifier: NCT01922791). Healthy women (n = 439) with overweight or obesity and gestational weeks (GW) < 18 were recruited in South–West Finland (October 2013–July 2017). Details of the study are described elsewhere [32]. The study was carried out according to the guidelines of the Declaration of Helsinki and each woman provided written informed consent before participation. The Ethics Committee of the Hospital District of South–West Finland approved the study protocol.

The original trial included a fish oil/probiotics (fish oil + placebo, probiotics + placebo, fish oil + probiotics, placebo + placebo) intervention [32]. Due to dropouts, we did not expect to detect any differences in a child's motor performance between the intervention groups and this was also confirmed (data not shown). Nonetheless, the intervention was considered as a confounder in the statistical analysis. Two study visits were arranged for the pregnant mothers: first in early (mean 13.7, SD 2.16 GW) and second in late (mean 35.2, SD 1.03 GW) pregnancy. During the visits, the mother's diet, adiposity, depressive and anxiety symptoms were assessed. Background information of the mothers and children was collected during the early pregnancy study visit or from hospital medical records. Physical activity of the women was determined by a questionnaire from which a metabolic equivalent index for physical activity (MET-index, h/wk) was calculated [33].

A follow-up of the study for 5–6-year-old children and their mothers was arranged between November 2020 and March 2023. In the follow-up visit, all those mothers who had completed both study visits during their pregnancies were asked to participate with their children. In this study, we included all children who completed or partly completed the Movement Assessment Battery for Children – Second Edition (Movement ABC-2) [34] during the 5–6 year study visits and their mothers, i.e. the sample was 159 child-mother dyads (Fig. 1).

2.2. Child-related variables

2.2.1. Motor outcome

The motor assessment of 5–6-year-old children was performed using the Movement ABC-2 during the study visit by researchers trained by child neurologist with several years' expertise of using this assessment method [34]. It contained three domains: manual dexterity (three items), aiming and catching (two items), and balance (three items). All items were scored according to the best attempt (out of a maximum of two attempts) with the values used as raw scores. Item scores were converted to standard scores equating to percentiles of each domain and total test scores, accordingly. Percentiles $\leq$15th for total scores were considered to denote DCD (motor impairment on subscales) with percentiles >15th representing age-appropriate motor development [34]. The

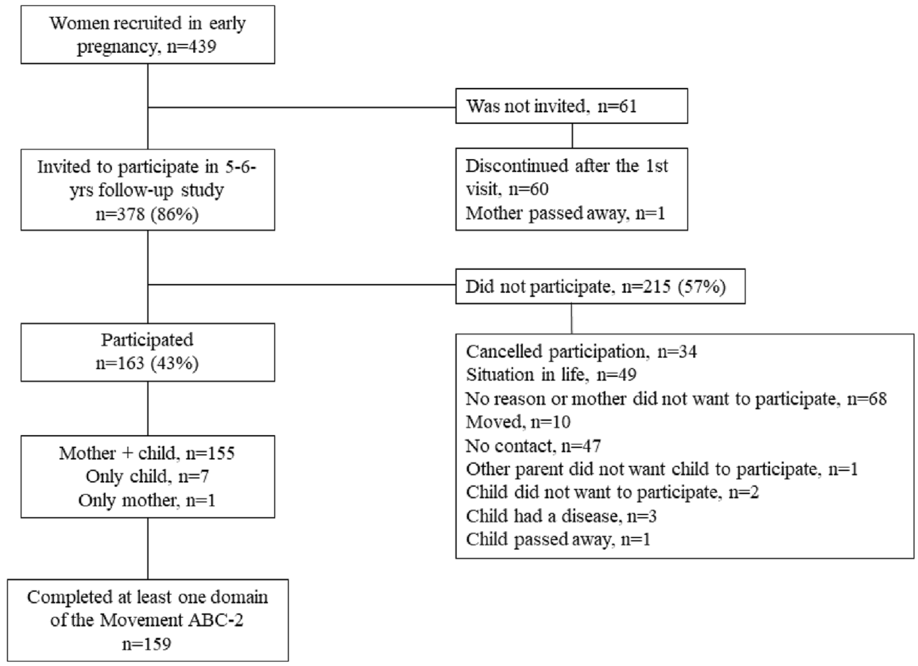

Fig. 1. Flow chart of the present study. Of the children, who participated in the 5–6 years follow-up study, 159 completed at least one domain of the Movement ABC-2. Movement ABC-2 = Movement Assessment Battery for Children, Second edition.

age band 1 (3–6 years) was used and the test was scored according to the test norms for 5–6-year-old children. In the analysis, percentiles as a continuous variable and as a dichotomous variable (DCD/motor impairment ≤15th vs no DCD/motor impairment >15th) were used. Higher percentiles indicated a better motor performance.

2.3. Overweight and obesity

Overweight status was defined based on the growth measures obtained during the 5–6-year study visit. Height was measured with a wall stadiometer to the nearest 0.1 cm and weight (kg) with an electronic scale (the Bod Pod system, software version 5.4.0, COSMED, Inc., Concord, CA). Weight-for-height% was calculated based on the Finnish growth charts [35], and was categorised as normal weight + underweight (<+10 %) and overweight + obesity (≥+10 %) [35]. Heigh and weight were available from 153/159 (96 %) children.

2.4. Physical activity

Physical activity was assessed by the triaxial ActiGraph wActiSleep-BT accelerometer (Pensacola, FL, USA). Children were instructed to wear the device on their non-dominant wrist for one week after the 5–6-year study visit. They were allowed to take the device off during the night and when taking a nap. The parents were asked to keep a diary in which they recorded their child's waking time and bedtime. ActiGraph data were downloaded and converted into 60-s epochs using ActiLife software (version 6.13, ActiGraph, Pensacola, FL). The vector magnitude counts/minute was used and calculated as the square root of the sum of squared activity counts of the three axes [36,37]. Accelerometer wear-time between the first and last recorded times in the diary was estimated and non-wear time was excluded using the Choi algorithm [38] and sleep-time by using the algorithm available in the ActiLife software [39]. Sedentary time was calculated using the cut-point value of ≤3958 vector magnitude counts/minute [40,41]. In the analysis, the mean of daily values for vector magnitude counts/minute was used as a measure of total physical activity and minutes as a measure of sedentary time. A valid measurement day was defined as waking wear-time ≥10 h. A total of 92 of the children wore the Actigraph accelerometer, and 79 of them had ≥4 valid days (mean 6.2, SD 1.0) with a mean 13.7 h of wear-time during waking time (SD 1.1). As DCD is linked with lower physical activity, we decided to evaluate this association in a subset of children in whom we had access to the ActiGraph data.

2.5. Maternal variables

2.5.1. Diet

The mothers filled in food diaries (2 weekdays, 1 weekend-day) from which two dietary patterns could be identified with principal component analysis as described previously [42]. The patterns were named as a healthier pattern (e.g. consumption of vegetables, fruits and berries, rye bread, pasta and rice, fish, margarine and oils) and as an unhealthier pattern (e.g. consumption of multigrain and wheat bread, desserts, pastries, sugary beverages, pasta and rice). Each woman (early pregnancy n = 154, late pregnancy n = 155) received a component coefficient score for both patterns, the pattern with the higher score being designated as her predominant diet. Fish consumption of mothers was assessed by a frequency questionnaire evaluating how many times they had consumed fish during the two weeks prior to the study visit (early pregnancy n = 159, late pregnancy n = 153).

2.6. Obesity and GDM

Maternal adiposity was defined by pre-pregnancy BMI (kg/m^2) and body composition. Pre-pregnancy BMI was categorized based on self-reported pre-pregnancy weight and height measured with a wall stadiometer to the nearest 0.1 cm during the early pregnancy study visit, and mothers were classified as having overweight or obesity (n = 159). The body composition was measured by air displacement plethysmography (the Bod Pod system, software version 5.4.0, COSMED, Inc., Concord, CA) according to the manufacturer's instructions. Participants were advised to fast overnight, not to drink <4 h before the measurements, not to exercise or to shower on the morning of the measurements and to wear tight underwear with a tight cap (early pregnancy n = 159, late pregnancy n = 156). The proportion of fat (%) was calculated from density using the formulas devised by van Raaij et al. [43] that consider the gestational length and the general swelling when necessary. Gestational weight gain during pregnancy was determined as follows: last measured weight minus self-reported pre-pregnancy weight.

GDM was diagnosed with a 75 g 2-h oral glucose tolerance test (OGTT) if one or more values were: 0h ≥ 5.3, 1 h ≥ 10.0 and 2 h ≥ 8.6 mmol/l. The test was conducted according to Finnish current care guidelines [44] that are in line with those issued in 2007 by the American Diabetes Association. The test was offered in the health care clinics and was conducted in mid-pregnancy (median 26.0 GW, IQR 25.0–27.3) and in early pregnancy (median 14.4 GW, IQR 13.0–16.2) for women at high-risk for GDM [44]. A total of 155 mothers underwent an OGTT test in early and/or mid pregnancy.

2.7. Depressive and anxiety symptoms

Maternal depressive and anxiety symptoms were assessed as reported previously [45]. Depressive symptoms were assessed using the Edinburgh Postnatal Depression scale (EPDS) that is a 10 item self-reported scale (early pregnancy n = 159, late pregnancy n = 157) [46]. The SCL-90/anxiety subscale questionnaire was used to assess the woman's general anxiety symptoms; this is a 10 item self-reported scale (early pregnancy n = 142, late pregnancy n = 153) [47]. In both questionnaires, a higher score indicated a higher prevalence of depressive or anxiety symptoms.

2.8. Statistical analysis

The normality of data was defined as skewness <1. Normally distributed variables were summarised as mean (standard deviation) while those not normally distributed were assessed as medians (interquartile range). Independent samples T-test or Mann Whitney U-test were used to assess differences between the groups with the continuous variables. Categorical variables were described as frequency (percentage) with the Fisher exact test being used in the comparisons.

General linear models were applied to investigate the associations between maternal exposures and motor performance as continuous percentiles of the Movement ABC-2 or between motor performance as dichotomous outcome (≤15th percentile) and physical activity. Logistic regression models were applied to assess the associations between maternal exposures and motor performance as a dichotomous outcome (≤15th percentile). Pearson (r) or the Spearman (rho) partial correlation coefficient were used to investigate correlations. The models were adjusted for maternal education, age, smoking status before pregnancy and for the child's sex, as these associated with percentiles for total test scores (or at least one sub-scale) in the Movement ABC-2 in the univariate analyses. In addition, the analyses were adjusted based on the associations between exposures and background variables: 1) GDM status: gestational age at delivery and pre-pregnancy BMI, 2) obesity status: GDM status, 3) early pregnancy body composition: gestational age at delivery, and 4) EPDS in early pregnancy: gestational age at delivery, EPDS in late pregnancy: primiparity. The original trial intervention groups (fish oil and/or probiotics) were included in the linear and logistic models. When studying the association between motor performance as a dichotomous outcome (≤15th percentile) and physical activity, the analyses were adjusted for the child's sex and accelerometer wear-time. No data imputation was performed. Statistical analyses were conducted using IBM SPSS Statistics version 27 for Windows (IBM Corp, Armonk, NY, USA). *P*-values <0.05 were considered statistically significant.

3. Results

3.1. Study participants

The Movement ABC-2 was performed in 159 children (Fig. 1), with the vast majority, 154 (97 %), completing all three subscales. The mean age of the children at the time of the Movement ABC-2 examination was 5.5 years and most children (116/153) had normal weight (Table 1). Children with DCD were more often boys (72.7 % vs 48.5 % in children without DCD, p = 0.04). The majority of all mothers were highly educated especially those of children without DCD. One in every five mother had been a smoker before pregnancy. Most mothers (62.9 %) were classified as having overweight and the rest (37.1 %) as having obesity based on their pre-pregnancy BMI. Every fifth woman was diagnosed with GDM in her current pregnancy (Table 1). No differences were detected in the clinical characteristics between the mothers or children who participated and in those who did not participate in the Movement ABC-2 assessment (Supplement Table 1).

The mean percentile for total scores of the Movement ABC-2 was 47.5 (SD 28.3); for the subscale of manual dexterity it was 40.8 (SD 28.9), for aiming and catching 46.9 (SD 27.2), and for balance 58.9 (SD 28.8). There were 22 (14.3 %) children designated as having DCD (scored ≤15th percentile). The proportion of children with percentiles ≤15th in the subscales were as follows; 14.6 % for aiming and catching, 24.7 % for manual dexterity, and 9.0 % for balance.

The accelerometer measurements were available for a subpopulation of 79 children; their mean daily physical activity was 4167 (SD 769) counts/minute and mean sedentary time 456 (SD 85.7) minutes. Percentiles ≤15th in manual dexterity associated with lower physical activity and higher sedentary time (Supplement Table 2). Children with DCD undertook less physical activity and had a higher sedentary time as compared to children without DCD. However, the differences were not statistically significant.

3.2. Maternal diet and child motor outcome at 5–6 years of age

A healthier dietary pattern during the early phase of the pregnancy was associated with higher percentiles for total scores and for aiming and catching subscale in the Movement ABC-2 (Table 2). There was no association between the healthier dietary pattern in early pregnancy and DCD (Table 3). In late pregnancy, dietary patterns were not associated with motor performance as assessed by the Movement ABC-2 (Tables 2 and 3).

We also investigated the maternal diet in more detail by evaluating fish consumption in early (median 2.0, IQR 1.0–3.0 times over 2 weeks prior to study visit) and late pregnancy (median 2.0, IQR 1.0–3.0 times over 2 weeks prior to study visit). A greater fish consumption in early pregnancy was related with lower odds for the child exhibiting impairments in manual dexterity (adjusted OR 0.72, 95 % CI 0.54–0.97, $p = 0.03$) as well as with impaired aiming and catching (adjusted OR 0.64, 95 % CI 0.44–0.94, $p = 0.02$). Fish consumption in late pregnancy did not associate with the motor outcome as assessed by the Movement ABC-2 (data not shown).

Table 1
Clinical characteristics of mothers and their children (n = 159), and according to the child's motor outcome assessed by the Movement ABC-2 at 5–6-years.

Mothers	All	Without DCD[a]	With DCD[a]	P
	n = 153–159	n = 128–132	n = 20–22	
Age (years), mean (SD)	30.6 (4.3)	30.9 (4.1)	29.6 (5.2)	0.17
College or university education, n (%)	107 (67.7)	94 (71.8)	11 (50.0)	0.049
Primiparity, n (%)	82 (51.6)	66 (50.0)	12 (54.5)	0.82
Smoking before pregnancy, n (%)	31 (19.6)	21 (16.0)	7 (31.8)	0.13
Pre-pregnancy BMI (kg/m^2), median (IQR)	28.8 (26.5–31.6)	28.7 (26.4–31.6)	29.3 (26.7–32.4)	0.30
Smoking during pregnancy, n (%)	7 (4.5)	6 (4.6)	9 (0.0)	0.59
Blood pressure (mmHg) early pregnancy				
Systolic, median (IQR)	115 (110–123)	115 (115–122)	117 (112–126)	0.26
Diastolic, median (IQR)	76 (71–81)	76 (71–81)	77 (71–83)	0.44
Physical activity (MET-index, h/wk) early pregnancy, median (IQR)	4.8 (3.0–12.0)	4.8 (3.0–12.0)	6.2 (3.0–12.0)	0.37
Gestational weight gain (kg), mean (SD)	13.1 (6.4)	12.7 (6.4)	14.5 (6.0)	0.23
Gestational weeks at delivery, median (IQR)	39.9 (39.1–40.9)	40.0 (39.1–40.8)	40.1 (39.0–40.7)	0.95
Unassisted vaginal delivery, n (%)	115 (72.3)	94 (71.2)	19 (86.4)	0.19
Children at delivery				
Sex, girl, n (%)	75 (47.2)	68 (51.5)	6 (37.3)	0.04
Born preterm (<37 + 0 GW), n (%)	7 (4.4)	7 (5.3)	0 (0.0)	0.59
Apgar 1 min, median (IQR)	9 (9–9)	9 (9–9)	9 (8–9)	0.12
Apgar 5 min, median (IQR)	9 (9–9)	9 (9–9)	9 (9–9)	0.73
Children at 5–6 years				
Age (years), mean (SD)	5.5 (0.5)	5.6 (0.45)	5.4 (0.44)	0.04
Normal weight or underweight, n (%)	116 (75.8)	98 (76.6)	13 (65.0)	0.28
Overweight or obesity[b], n (%)	37 (24.2)	30 (23.4)	7 (35.0)	

Data are presented as mean (SD) for normally distributed variables, median (IQR) for non-normally distributed variables, and n (%) for categorical variables. Independent samples T-test for normally distributed variables, Mann Whitney U-test for non-normally distributed variables and Fisher exact test for categorical variables.
BMI=Body mass index, DCD = Developmental coordination disorder, GW=Gestational weeks, IQR = interquartile range, Movement ABC-2 = Movement Assessment Battery for Children, Second Edition, SD = standard deviation.
[a] DCD based on total test scores (≤15th percentile), n = 154.
[b] Weight-for-height%: normal weight or underweight <+10 %, overweight or obesity ≥+10 %.

Table 2
Adjusted general linear models on the associations between dietary patterns (early and late pregnancy), gestational diabetes mellitus (GDM) and obesity status and motor performance (percentiles of the Movement ABC-2) of the children at the age of 5–6-years.

	Total test score		Manual Dexterity		Aiming & Catching		Balance	
	Adjusted mean (SE)	Adjusted mean difference (95 % CI)	Adjusted mean (SE)	Adjusted mean difference (95 % CI)	Adjusted mean (SE)	Adjusted mean difference (95 % CI)	Adjusted mean (SE)	Adjusted mean difference (95 % CI)
Dietary patterns								
Early pregnancy								
Healthier	49.5 (4.05)	9.80 (0.64–19.0)	42.7 (4.17)	4.95 (−4.46–14.3)	50.9 (3.77)	9.57 (0.95–18.2)	55.7 (4.09)	5.20 (−4.17–14.6)
Unhealthier	39.7 (3.55)		37.7 (3.64)		41.3 (3.34)		50.5 (3.60)	
Late pregnancy								
Healthier	44.3 (3.86)	1.16 (−8.00–10.3)	37.0 (3.73)	−3.03 (−12.1–6.05)	47.9 (3.52)	4.05 (−4.51–12.6)	52.7 (3.90)	0.41 (−8.82–9.64)
Unhealthier	43.1 (3.87)		40.0 (3.85)		43.8 (3.58)		52.3 (3.85)	
GDM status (any stage of pregnancy)								
Without GDM	43.3 (3.29)	2.52 (−8.65–13.7)	40.1 (3.38)	−1.28 (−12.7–10.1)	43.3 (3.11)	5.52 (−5.08–16.1)	43.3 (3.11)	−1.51 (−12.9–9.85)
With GDM	45.8 (5.30)		38.8 (5.30)		48.8 (4.92)		51.2 (5.37)	
Obesity status								
With overweight	44.9 (4.03)	−2.17 (−12.0–7.61)	38.3 (4.01) 40.6 (4.38)	2.26 (−7.59–12.1)	46.0 (3.76)	−1.20 (−10.5–8.12)	53.9 (3.99)	−6.37 (−16.1–3.41)
With obesity	42.7 (4.47)				44.8 (4.15)		47.5 (4.48)	

Data are presented as adjusted means (SE), adjusted mean difference (95 % CI).
General linear models adjusted for:
Dietary patterns: maternal education, age, smoking before pregnancy, child's sex, and intervention groups. Adjusted mean difference healthier−unhealthier. Early pregnancy, healthier n = 66–68, unhealthier n = 84–85, late pregnancy healthier n = 72–75, unhealthier n = 90–91.
GDM status: maternal education, age, pre-pregnancy BMI, smoking before pregnancy, child's sex, gestational weeks at delivery and intervention groups. Adjusted mean difference with GDM−without GDM. Without GDM n = 114–115, with GDM n = 36–38.
Obesity status: maternal education, age, smoking before pregnancy, child's sex, GDM status and intervention groups. Adjusted mean difference with obesity−with overweight. Obesity n = 57–59, overweight n = 97–99.
CI=Confidence Interval, GDM = Gestational diabetes mellitus, Movement ABC-2 = Movement Assessment Battery for Children, Second Edition, SE = standard error.
Overweight pre-pregnancy BMI = 25–29.9 kg/m^2 and obesity pre-pregnancy BMI ≥30 kg/m^2. Early pregnancy: mean 13.7 SD 2.16 gestational weeks, late pregnancy: mean 35.2 SD 1.03 gestational weeks. Higher percentiles indicate better motor performance.

3.3. Maternal adiposity, pre-pregnancy BMI, GDM and child motor outcome at 5–6 years of age

The maternal obesity or GDM status did not associate with motor performance assessed by the Movement ABC-2 (Tables 2 and 3). We examined maternal obesity in more detail by measuring the body composition in early (fat mass 36.5 ± 9.3 kg, fat percentage 43.1 ± 5.49 %) and late (fat mass 37.8 ± 9.3 kg, fat percentage 40.5 ± 5.4 %) pregnancy. A higher fat mass in early and late pregnancy as well as a higher fat percentage in late pregnancy, but not in early pregnancy, associated with an increased odds for DCD (Table 3). Similarly, every 1 % increase in the fat percentage in late

Table 3
Adjusted logistic regression models on the associations between maternal dietary patterns, gestational diabetes mellitus (GDM) and obesity status, adiposity and motor outcome (≤15th percentile) of the children assessed by the Movement ABC-2.

	Total test score		Manual Dexterity		Aiming & Catching		Balance	
Percentiles	n (%) ≤15 >15	Adjusted OR (95 % CI)	n (%) ≤15 >15	Adjusted OR (95 % CI)	n (%) ≤15 >15	Adjusted OR (95 % CI)	n (%) ≤15 >15	Adjusted OR (95 % CI)
Early pregnancy								
Dietary patterns								
Healthier	10 (15.2) 56 (84.8)	1.16 (0.43–3.17)	13 (19.1) 55 (80.9)	0.63 (0.28–1.41)	8 (11.8) 60 (88.2)	0.58 (0.21–1.55)	4 (6.0) 63 (94.0)	0.45 (0.12–1.70)
Unhealthier	11 (13.1) 73 (86.9)		23 (27.1) 62 (72.9)		14 (16.5) 71 (83.5)		9 (8.6) 75 (89.3)	
GDM status (any stage of pregnancy)								
With GDM	17 (14.9) 97 (85.1)	0.70 (0.19–2.57)	28 (24.1) 88 (75.9)	0.99 (0.37–2.63)	16 (13.8) 100 (86.2)	1.33 (0.44–4.05)	11 (9.6) 104 (90.4)	0.58 (0.10–3.21)
Without GDM	5 (13.9) 31 (86.1)		10 (26.3) 28 (73.7)		7 (18.4) 31 (81.6)		3 (8.4) 33 (91.7)	
Obesity status								
With overweight	12 (12.4) 85 (87.6)	2.02 (0.72–5.64)	24 (24.2) 75 (75.8)	1.04 (0.45–2.40)	17 (17.2) 82 (82.8)	0.47 (0.16–1.39)	6 (7.1) 91 (92.9)	2.50 (0.72–8.70)
With obesity	10 (17.5) 47 (82.5)		15 (25.5) 44 (74.6)		6 (10.2) 53 (89.8)		7 (12.8) 50 (91.0)	
Adiposity								
Fat mass (kg)	–	1.07 (1.01–1.13)	–	1.02 (0.98–1.06)	–	1.00 (0.95–1.05)	–	1.06 (0.995–1.12)
Fat percentage	–	1.10 (0.99–1.22)	–	1.03 (0.96–1.11)	–	0.97 (0.89–1.06)	–	1.10 (0.98–1.24)
Depression & anxiety								
EPDS	–	0.92 (0.79–1.07)	–	1.03 (0.93–1.15)	–	0.78 (0.65–0.93)	–	0.89 (0.74–1.08)
SCL-90	–	0.96 (0.82–1.13)	–	1.04 (0.93–1.16)	–	0.85 (0.69–1.05)	–	1.02 (0.87–1.20)
Late pregnancy								
Dietary patterns								
Healthier	11 (15.3) 61 (84.7)	0.98 (0.38–2.53)	22 (29.3) 53 (70.7)	1.68 (0.78–3.63)	10 (13.3) 65 (86.7)	0.85 (0.33–2.18)	8 (11.1) 64 (88.9)	1.47 (0.46–4.66)
Unhealthier	11 (14.1) 67 (85.9)		15 (19.0) 64 (81.0)		12 (15.2) 67 (84.8)		6 (7.6) 73 (92.4)	
Adiposity								
Fat mass (kg)	–	1.08 (1.02; 1.14)	–	1.04 (0.997; 1.08)	–	1.00 (0.96; 1.06)	–	1.05 (0.99; 1.11)
Fat percentage	–	1.12 (1.01–1.24)	–	1.09 (1.01–1.18)	–	0.99 (0.90–1.08)	–	1.06 (0.95–1.19)
Depression & anxiety								
EPDS	–	0.87 (0.75–1.00)	–	1.03 (0.93–1.13)	–	0.82 (0.70–0.96)	–	0.93 (0.79–1.10)
SCL-90	–	0.86 (0.69–1.06)	–	0.98 (0.85–1.12)	–	0.83 (0.67–1.03)	–	1.03 (0.84–1.25)

Data are presented as frequencies (percentage), adjusted OR (95 % CI).
Logistic regression models adjusted for:
Dietary patterns: maternal education, age, smoking before pregnancy, child's sex, and intervention groups. Unhealthier dietary pattern as a reference category.
GDM status: maternal education, age, pre-pregnancy BMI, smoking before pregnancy, child's sex, gestational weeks at delivery, intervention groups. Without GDM as a reference category.
Obesity status: maternal education, age, smoking before pregnancy, child's sex, GDM status, and intervention groups. Overweight as a reference category.
Body composition: maternal education, age, smoking before pregnancy, child's sex, and intervention groups and additionally models on early pregnancy fat mass and fat percentage for gestational weeks at delivery. Early pregnancy n = 154–158, late pregnancy n = 151–155.
Depression (EPDS): maternal education, age, smoking before pregnancy, child's sex, and intervention groups and additionally models on EPDS in early pregnancy for primiparity and models on EPDS in late pregnancy for gestational weeks at delivery. Early pregnancy n = 145–158, late pregnancy n = 152–156.
Anxiety (SCL-90): maternal education, age, smoking before pregnancy, child's sex, and intervention groups. Early pregnancy n = 137–141, late pregnancy n = 148–152.
CI=Confidence Interval, EPDS = Edinburgh Postnatal Depression Scale, GDM = gestational diabetes mellitus, Movement ABC-2 = Movement Assessment Battery for Children, Second Edition, OR=Odds Ratio, SCL-90 = Anxiety subscale of Symptoms Checklist.
Overweight pre-pregnancy BMI = 25–29.9 kg/m^2 and obesity pre-pregnancy BMI ≥30 kg/m^2. Early pregnancy: mean 13.7 SD 2.16 gestational weeks, late pregnancy: mean 35.2 SD 1.03 gestational weeks.

pregnancy increased by 9 % the odds that the children would be in the ≤15th percentile for manual dexterity (Table 3).

3.4. Maternal depression, anxiety and child's motor outcome at 5–6 years of age

The mean EPDS score in early pregnancy was 4.5 (SD 3.7) and slightly lower, 4.1 (SD 3.9), in late pregnancy. Higher scores in EPDS in both early and late pregnancy were associated with decreased odds for the child being in the ≤15th percentile for aiming and catching at 5–6 years (Table 3). The results were confirmed by using continuous variables. Positive correlations were detected between early pregnancy EPDS scores and percentiles for the aiming and catching (r = 0.20, adj.p = 0.02) subscale and between late pregnancy EPDS scores and percentiles for total scores (r = 0.23, adj.p = 0.01), aiming and catching (r = 0.20, adj.p = 0.02) and balance (r = 0.26, adj.p = 0.001) subscales.

The median SCL-90 score in early pregnancy was 2.0 (IQR 0.75–4.0) and it remained the same in late pregnancy, 2.0 (0.0–4.0). No associations were observed between SCL-90 scores and the child's later motor outcome assessed by the Movement ABC-2 (Table 3). Interestingly, positive correlations were detected between SCL-90 scores in late pregnancy and percentiles for total scores (rho = 0.23, adj.p = 0.01) and the manual dexterity subscale (rho = 0.20, adj.p = 0.02).

4. Discussion

4.1. Summary of the findings

In this prospective study which focused on mothers with pre-pregnancy overweight or obesity and their children, 14 % of the children had DCD at the age of 5–6-years, which is almost three times higher than in the general population (5–6 %) [1]. It was evident that both higher maternal body fat mass and percentage were associated with increased odds for her child to exhibit signs of DCD. Importantly we observed that this association may be mediated by the mother's diet as a healthier dietary pattern during pregnancy was associated with better motor performance at 5–6 years. The mental status during pregnancy appeared to be associated with the child's motor development, but surprisingly, a higher level of maternal depressive symptoms was related to better motor development. Children with an impaired motor development undertook less physical activity than those with age-appropriate motor development at 5–6 years. However, the association was statistically significant only for their manual dexterity. Nevertheless, this is in line with previous knowledge about motor impairment and its association with decreased physical activity [2].

4.2. Maternal diet and child motor development at 5–6 years of age

We demonstrated that those children whose mothers had adhered to a healthier dietary pattern during early pregnancy had a better overall motor performance when they were 5–6-years-old. We also detected that a higher consumption of fish, again in early pregnancy, associated with a child's lower odds for impairments in his/her motor development. In line with our findings, a higher maternal adherence to a seafood-rich dietary pattern and fish consumption in pregnancy have been linked with better gross and fine motor performance in 1-year-old children [28,48]. In contrast to our trial, both of the above publications included also pregnant women with normal weight and the assessment methods were different from ours (Bayley-III Screening Test and the Ages & Stages Questionnaires). The nutritional content of a healthier dietary pattern could explain its association with better motor performance as this pattern included a high consumption of vegetables, fruits and berries, and fish/seafood. These food groups are rich in various nutrients, e.g. folate and iodine that are vital for foetal brain development [49,50]. Indeed, we also demonstrated that a higher maternal fish consumption was associated with better motor performance by her child; it could be speculated that this is attributable to the long-chain polyunsaturated fatty acids present in fish, as these are important nutrients for the developing brain [51].

4.3. Maternal adiposity, GDM and child motor development at 5–6 years of age

One novelty in our study arises from detecting a link between the maternal body composition and motor performance in 5–6-year-old children; a higher maternal body fat mass and percentage were associated with higher odds for the DCD. This finding is in line with our previous report examining 2-year-old children from the same study cohort showing that higher body fat percentage of the mother was associated with poorer gross motor skills in the child [52]. There is also report of an increased risk for gross motor delay in children up to 5-years-old born to mothers with obesity [13]. One putative mechanism linking maternal obesity to a less favourable neurodevelopment may relate to the presence of a systemic low-grade inflammation induced by the excess adipose tissue. Inflammatory markers can cross the placenta and influence brain development during the foetal period [53]. Body composition measurement is a more accurate way than BMI to assess adiposity. Nonetheless, we did not detect any association between maternal obesity, defined by pre-pregnancy BMI, and motor performance. Furthermore, GDM did not affect the children's motor performance, which is in accordance with some [12,13,17] but not all prior studies [54]. Based on our current and a previous report [52], it could be suggested that maternal adiposity, i.e. a higher body fat mass/percentage already before pregnancy, rather than GDM, plays a more pivotal role in affecting the offspring's later motor performance.

4.4. Maternal depression, anxiety and the child's motor development at 5–6 years of age

An unexpected finding emerging from this study was that especially higher levels of maternal depressive but also anxiety symptoms were associated with better motor performance in the children. Previously, some investigators have linked elevated stress or depressive and anxiety symptoms with better motor skills in 1–2-year-old children [55–57], although others have reported opposite findings [21–23,58]. Nevertheless, the underlying mechanisms are not fully understood. It has been suggested that maternal stress during pregnancy could lead to faster developmental strategies in the child [59]. This might be attributable to the elevated glucocorticoid levels in response to stress [60]. Cortisol is known to have an important role in the foetal brain development, and its increased level in late pregnancy has been shown to accelerate cognitive development in 1-year-old infants [61]. However, it is noteworthy that most women in our current study scored low in both depression and anxiety questionnaires, and hence the clinical relevance of our result is unclear.

4.5. Strengths and limitations

The major strength of our study was its prospective design with a long-term follow-up of mothers and children from early pregnancy until 5–6 years, although this is typically linked with dropouts over the course of the study. However, no significant differences were evident in the dropout analyses between the women (Supplement Table 1). The motor assessment was performed using the latest version of the Movement ABC-2 with age-adjusted scores applied in the analyses, and with the children's physical activity being measured objectively using the Actigraph accelerometer to confirm the potential association between motor performance and physical activity in a subpopulation of the children. An air displacement plethysmography was used to measure the women's body composition; this is the gold-standard method as it estimates more precisely adiposity than can be obtained with a BMI value. We chose to study women with overweight or obesity, a group prone to experience various pregnancy-related complications. This is a putative limitation as it may affect the generalizability of our results. However, our study population represents relatively well pregnant women visiting maternal welfare-clinics in Finland [9].

A possible limitation was that over half of the women in our study were highly-educated. Therefore, the educational-level was included in the analysis as a confounding factor. Another limitation may arise from the fact that our sample size was relatively small, which might affect the generalizability of the results. The statistical power was not calculated for this sub study of the original mother-child trial. However, as we inspected associations the current approach is appropriate and the results may be also used in planning interventions.

4.6. Conclusions

In this prospective follow-up study of mothers with overweight/obesity the prevalence of DCD in their 5–6-year-old children was higher than in the general population [1]. Higher maternal adiposity increased the risk for DCD in the child, whereas a healthier dietary pattern associated with his/her better motor performance. Our results highlight the importance of targeting dietary counselling in maternal clinics throughout the pregnancy, especially to women at high-risk for pregnancy complications due to overweight/obesity. This would likely benefit not only mothers.g. by reducing the excess weight-gain and lowering their GDM risk, but also their children by supporting their long-term motor development.

Author contributions

Lotta Saros: Data curation, Formal analysis, Investigation, Visualization, Writing – original draft; Sirkku Setänen: Conceptualization, Investigation, Methodology, Supervision, Writing – review & editing; Janina Hieta: Data curation, Investigation, Writing – review & editing; Eeva-Leena Kataja: Writing – review and editing; Kristin Suorsa: Writing – review and editing; Tero Vahlberg: Writing – review and editing; Kristiina Tertti: Writing – review and editing; Harri Niinikoski: Writing – review and editing; Sari Stenholm: Writing – review and editing; Tuomas Jartti: Writing – review and editing; Kirsi Laitinen: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – review and editing.

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Declaration of competing interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clnesp.2025.01.047.

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