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ORIGINAL PAPER

The impact of maternal gestational diabetes on a child's psychomotor development up to the age of 2 – from a delayed start to accelerated growth

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ABSTRACT

Introduction: The psychomotor development of children born to mothers with gestational diabetes mellitus (GDM) has been extensively studied, yielding mixed results. This study aimed to statistically evaluate the impact of GDM on the psychomotor development of children up to two years of age in a local Polish population, using the global scale of early development (GSED) – a modern assessment tool recommended by the World Health Organization.
Material and methods: The analysis included 662 children (aged 1–24 months) with complete clinical data participating in the regional program entitled Coordinated and comprehensive family support in specialist counseling, prevention, diagnosis, and elimination of developmental irregularities in children up to 2 years of age in the Opole Voivodship, Poland. Psychomotor development was assessed using milestones from the GSED and summarized using the unidimensional developmental score (D-score). Developmental outcomes were expressed as D-scores and standardized developmental scores/development-for-age Z-scores (DAZ). Changes in DAZ over time by gestational age and presence of GDM were analyzed using multilevel modeling.
Results: Among preterm infants, those born to mothers with GDM initially showed delayed psychomotor development; however, they exhibited a significantly faster developmental trajectory ($p < 0.05$) compared to full-term children. The findings indicate a dynamic increase in DAZ among preterm infants exposed to GDM, suggesting a compensatory "catch-up" in development over time.
Conclusions: Offspring of mothers with GDM demonstrate an early developmental delay followed by a phase of accelerated growth, in contrast to the offspring of mothers without GDM, whose development follows a more stable trajectory. These findings underscore the importance of accounting for gestational age when evaluating the impact of GDM on child development.

KEY WORDS:

gestational diabetes mellitus, D-score, psychomotor development of children, global scale of early development.

INTRODUCTION

Gestational diabetes mellitus (GDM) is one of the most common complications of pregnancy. According to the World Health Organization (WHO), GDM is defined as carbohydrate intolerance that is first recognized or diagnosed during pregnancy [1, 2]. In Poland, the prevalence of GDM is 3–12% of all pregnancies, comparable to the rate reported in the United States (approximately 9%) [2].

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TABLE 1. Descriptive statistics of offspring included in the program, along with Mann-Whitney *U* test results for differences in birth weight

Group	*n*	Mean	Median	Interquartile range	Minimum	Maximum	*p*-value
Sex							
Male	327	3400	3440	600	1600	4920	–
Female	335	3284	3260	580	1620	4640	0.0013
GDM (–)	503	3334	3340	630	1620	4680	–
GDM (+)	99	3361	3320	450	1800	4920	0.5915
NA	56	–	–		–	–	–
Preterm infants	50	2673	2610	572.5	1600	4050	–
Full-term infants	605	3397	3380	560	2180	4920	< 0.0001
NA	3	–	–		–	–	–

The increasing prevalence of GDM is closely linked to the global obesity epidemic, advanced maternal age, and reduced physical activity levels across populations [3]. The morbidity associated with GDM continues to rise and poses risks not only to the affected women but also to their offspring. A fetus developing in the altered metabolic environment of a diabetic mother is exposed to multiple risk factors that may interfere with normal development. The reported incidence of congenital anomalies in infants born to mothers with diabetes is 2.7–16.8% [4, 5].

Newborns of women with GDM are at elevated risk for early complications such as macrosomia, birth trauma, hypoglycemia, hypomagnesemia, hypocalcemia, hyperbilirubinemia, respiratory distress, and hematological or cardiac disorders, including increased risk of perinatal mortality [6]. Long-term consequences may include an increased risk of metabolic syndrome, obesity, insulin resistance, and diabetes, as well as delays in speech, motor development, and cognitive functioning [7–9].

The aim of this study was to statistically assess the impact of GDM on the psychomotor development of children up to two years of age in a local Polish population, using the global scale of early development (GSED) [10, 11], a validated, modern assessment tool recommended by the WHO.

MATERIAL AND METHODS

Participant recruitment was conducted as part of the regional program entitled *Coordinated and comprehensive family support in specialist counseling, prevention, diagnosis, and elimination of developmental irregularities in children up to 2 years of age*. The program was conducted from January 1, 2020 to September 30, 2023. Children were eligible for inclusion in the study if they met the following criteria:

1. Age 1–24 months at the time of assessment;
2. Residence within the Opole Voivodeship during the study period;
3. Provision of written informed consent by the child's legal guardian;
4. Availability of complete perinatal medical records, including information on maternal health during pregnancy (to assess GDM status).

A total of 662 children were examined as part of the program.

This retrospective study did not require approval from the bioethics committee (statement from the Bioethics Committee of the University of Opole, Ref. No. 83800.0052.23.2025). It was conducted in accordance with ethical guidelines, ensuring full confidentiality and anonymity of patient data. The study design involved no risk or burden to participants, and all data protection procedures adhered to applicable legal and institutional standards.

In the preliminary analysis, due to deviations in offspring birth weight from a normal distribution (Shapiro-Wilk test, $p < 0.0001$), differences by sex, GDM status, and gestational age at birth were evaluated using the Mann-Whitney *U* test (Table 1, Figure 1).

According to the results of the Mann-Whitney *U* test (Table 1), statistically significant differences in birth weight ($p < 0.05$) were observed between sexes and between term and preterm births. No significant difference in birth weight was found based on maternal GDM status. Additional details are presented in Figure 1 A–C.

Figure 1 A compares birth weight by sex (male vs. female). The results indicate that male infants had slightly higher birth weights than female infants, with a statistically significant difference ($p = 0.0013$). Panel B illustrates the relationship between maternal GDM and birth weight. No statistically significant difference was observed between infants born to mothers with and without GDM ($p = 0.6275$). Panel C presents birth weight according to gestational age. A significant difference was found, with preterm infants exhibiting substantially lower birth weights compared to those born at term.

Psychomotor development was assessed using milestones incorporated into the GSED and summarized using the unidimensional developmental score (D-score). The global scale of early development comprises 139 items designed to evaluate emerging skills across cognitive, mo-

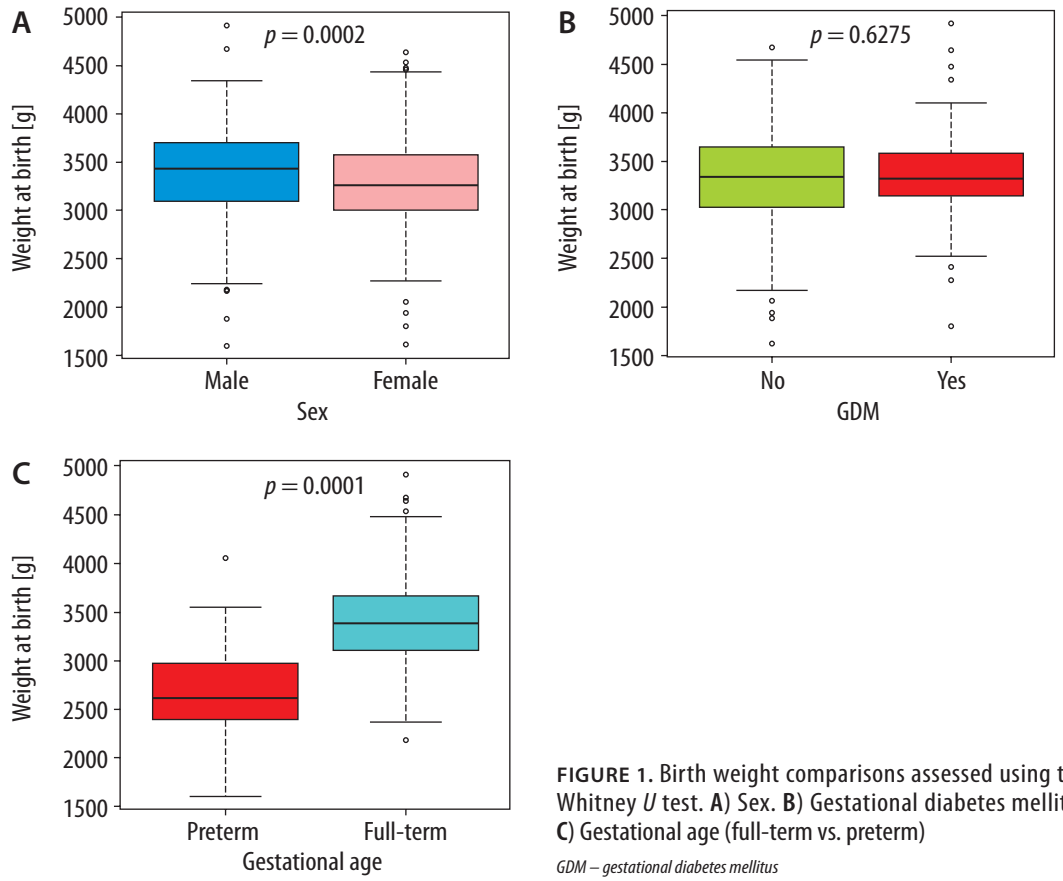

FIGURE 1. Birth weight comparisons assessed using the Mann-Whitney *U* test. **A**) Sex. **B**) Gestational diabetes mellitus status. **C**) Gestational age (full-term vs. preterm)

GDM – gestational diabetes mellitus

tor, language, and socio-emotional domains. Caregivers respond to binary questions (Yes/No, or Don't Know) based on age-appropriate performance criteria. The items are hierarchically ordered by difficulty, reflecting the progressive nature of early child development.

For the purposes of this study, 44 items were selected to represent the most relevant developmental skills observed in the Polish pediatric population during milestone assessments (Table 2).

Instruments such as the GSED enable the collection of new, population-based data essential for establishing developmental norms in healthy children and for monitoring national progress toward global early childhood development goals, as measured by the developmental score, or D-score [12]. The developmental score is an interval-scale unit that summarizes child development as a single continuous measure across time. Just as height (measured in centimeters) and weight (in kilograms) increase as a child grows, development – measured in D-score units – rises with age as the child acquires new skills.

The developmental score is a unidimensional measure that assumes dichotomous responses to developmental milestones, where each item is scored as 1 = PASS or 0 = FAIL. Responses are based on a set of age-appropriate items (e.g., "Can the child stack two blocks?" or "Does the child use two-word sentences?"), enabling standardized comparison across individuals and populations.

Conceptually, a child's D-score falls along a developmental continuum – beginning with simple skills and behaviors the child has already mastered and extending toward more complex abilities yet to be acquired. The developmental milestones that constitute the D-score are calibrated according to the Rasch model [13], ensuring a scale with interval properties and a fixed unit of measurement. The developmental score is calculated as the mean of the posterior distribution, conditional on the child's observed responses, the difficulty level of each item, and the child's age. It represents a unidimensional latent variable that captures a child's overall developmental progress during the first three years of life, encompassing multiple domains.

The developmental score can be standardized into the development-for-age Z-score (DAZ), which adjusts for age-related changes in developmental performance. The development-for-age Z-score is age-independent and scaled such that, at each age, scores follow a normal distribution with a mean of 0 and a standard deviation of 1. By accounting for the natural increase in D-score with age, the DAZ enables meaningful comparisons across age groups and between populations.

For the statistical analysis, we employed a longitudinal framework in which DAZ scores were modeled as a function of age, stratified by GDM status and pregnancy duration – specifically, preterm (< 37 weeks) vs. full-term (≥ 37 weeks) births. Given the nested structure of the data and the expectation of random variability across individual developmental trajectories, multilevel (hierarchical) modeling was applied.

TABLE 2. Selected psychomotor milestones used for assessing child development in the Polish population, including corresponding global scale of early development instrument codes

No.	Code	Issue
Gross motor skills		
1.	gs1moc002	When lying on his/her back, does your child move his/her arms and legs?
2.	gs1moc025	When your child is on his/her stomach, can he/she turn his/her head to the side?
3.	gs1moc028	Does your child hold his/her hands in fists all the time?
4.	gs1moc030	When held in a sitting position, can the child hold his/her head steady and straight?
5.	gs1moc031	When your child is on his/her stomach, can he/she hold his/her head up off the ground?
6.	gs1moc033	When he/she is on his/her tummy, can your child hold his/her head straight up, looking around for more than a few seconds? He/she can rest on his/her arms while doing this.
7.	gs1moc034	Can your child roll from his/her back to stomach or stomach to his/her side?
8.	gs1moc038	Can your child sit with support, either leaning against something (furniture or person), or by leaning forward on his or her hands?
9.	gs1moc041	When lying on his/her stomach, can your child hold his/her head and chest off the ground using only his/her hands and arms for support?
10.	gs1moc043	When lying on his/her back, does the child grab his/her feet?
11.	gs1moc048	Does your child intentionally move or change his/her position to get objects that are out of reach?
12.	gs1moc057	Can your child pull themselves up from the floor while holding onto something? For example, can they pull themselves up using a chair, a person, or some other object?
13.	gs1moc064	Can your child stand up without holding onto anything, even if just for a few seconds?
14.	gs1moc066	Can your child maintain a standing position on his/her own, without holding on or receiving support?
Small motor skills		
15.	gs1cgc032	Does your child show interest in new objects that are put in front of him/her by reaching out for them?
16.	gs1moc005	Does your child grasp your finger if you touch his/her hand?
17.	gs1moc015	Does your child grasp onto a small object (e.g., your finger, a spoon) when put in his/her hand?
18.	gs1moc018	While your child is on his/her back, can he/she bring his/her hands together?
19.	gs1moc035	Can your child reach for AND HOLD an object, at least for a few seconds?
20.	gs1moc039	Does your child try to reach for objects that are in front of him/her by extending one or both arms?
21.	gs1moc040	Can your child pick up a small object (e.g., a small toy or small stone) using just one hand?
22.	gs1moc051	Can your child pass a small object from one hand to the other?
23.	gs1moc052	Can your child bang objects together, or bang an object on the table or on the ground?
24.	gs1moc054	Can your child pick up and drop a small object (e.g., a small toy or small stone) into a bucket or bowl while sitting?
25.	gs1moc056	Can your child pick up a small object (e.g., a piece of food, small toy or small stone) with just his/her thumb and one finger?
Communication speech language		
26.	gs1lgc014	Does your child turn his/her head towards your voice or some noise?
27.	gs1lgc016	Does your child make sounds other than crying?
28.	gs1lgc037	Does your child make single sounds like 'buh' or 'duh' or 'muh'?
29.	gs1lgc058	Does your child stop what he/she is doing when you say 'Stop!' even if just for a second?
30.	gs1lgc062	Does your child make a gesture to indicate 'No' (e.g., shaking head)?
31.	gs1lgc071	Can your child follow a simple spoken command or direction without you making a gesture?
32.	gs1lgc072	Can your child fetch something when asked?
33.	gs1sec003	Does your child look at your face when you speak to him/her?
34.	gs1sec009	Does your child smile when you smile or talk with him/her?

TABLE 2. Cont.

No.	Code	Issue
Cognitive functions		
35.	gs1cgc006	Does your child look at and focus on objects in front of him/her?
36.	gs1cgc042	If an object falls to the ground out of view, does your child look for it?
37.	gs1cgc046	Does the child look for an object of interest when it is removed from sight or hidden from him/her (e.g., put under a cover, behind another object)?
Socio-emotional functions		
38.	gs1lgc004	Does your child cry when he/she is hungry, wet, tired, or wants to be held?
39.	gs1lgc012	When you talk to your child, does he/she smile, make noises, or move arms, legs or trunk in response?
40.	gs1lgc020	Does your child make noise or gesture to get your attention?
41.	gs1lgc023	Does your child laugh?
42.	gs1sec011	Does your child stop crying or calm down when you come to the room after being out of sight, or when you pick him or her up?
43.	gs1sec022	Does your child recognize you or other family members (e.g., smile when they enter a room or move toward them)?
44.	gs1sec024	Does your child smile or become excited when seeing someone familiar?

Multilevel models extend traditional linear models by incorporating random effects at different levels of the data hierarchy, thereby accounting for intra-individual and inter-individual variability. These models are well-suited for longitudinal data and are often referred to as mixed-effects models, as they include both fixed effects (e.g., GDM status, gestational age) and random effects (e.g., individual-specific developmental variation) [14].

In the proposed model, DAZ scores were analyzed as a function of age using linear regression with an interaction term to account for the effect of GDM over time (DAZ = age × GDM). Regression coefficients were considered statistically significant at a p-value < 0.05. All statistical analyses were performed using the MASS package [15] within the R statistical computing environment [16].

RESULTS

Figure 2 presents D-score trajectories by age for infants born to mothers with and without GDM, based on a subset of GSED items (Table 2). The analysis includes 503 GDM-negative and 99 GDM-positive infants.

The chart illustrates the relationship between child age and the D-score – a composite measure of psychomotor development encompassing motor, cognitive, and socio-emotional domains. Each curve represents an individual child's developmental trajectory over time. Blue lines indicate children of mothers without GDM, while red lines indicate children of mothers with GDM.

As expected, D-scores increase with age, reflecting developmental progression. While an overall upward trend is visible in both groups, substantial overlap exists between the GDM-positive and GDM-negative trajectories. This observation supports the use of age-standardized scores, such as the DAZ, to assess developmental differences independently of age.

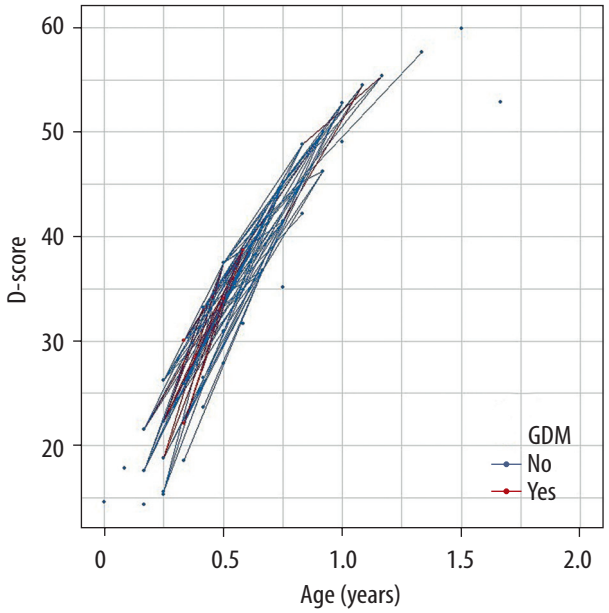

FIGURE 2. Developmental score estimates by age for infants born to mothers with/without gestational diabetes mellitus
D-score – developmental score, GDM – gestational diabetes mellitus

Estimates of multilevel regression coefficients for DAZ, including interaction terms between age and GDM status, stratified by gestational age (preterm < 37 weeks vs. full-term ≥ 37 weeks), are presented in Table 3 and visualized in Figure 3.

Figure 3 presents modeled developmental trajectories (DAZ scores) by age for individual infants, stratified by gestational age and maternal GDM status. Each line represents the statistically estimated developmental course of a single child over the observation period, categorized by GDM exposure. Panel A displays developmental pat-

TABLE 3. Results of multilevel regression analysis of the development-for-age Z-score, including interaction terms between age and gestational diabetes mellitus, stratified by gestational age: preterm (< 37 weeks) and full-term (≥ 37 weeks) births. A) Preterm infants (< 37 weeks). B) Full-term infants (≥ 37 weeks)

Infant	Parameter	Mean	Standard error	*p*-value
Preterm	Intercept	0.28	0.22	0.2160
	Age	0.07	0.40	0.8585
	GDM	–1.76	0.80	0.0323
	Age × GDM	4.50	1.73	0.0170
Full-term	Intercept	0.13	0.07	0.0424
	Age	0.52	0.13	0.0001
	GDM	–0.31	0.19	0.0942
	Age × GDM	0.83	0.40	0.0372

GDM – gestational diabetes mellitus

terns in preterm infants (< 37 weeks), comparing those exposed to GDM (red line) with those not exposed (blue line). Among children of mothers without GDM, DAZ trajectories remain relatively flat over time. In contrast, children exposed to GDM exhibit greater variability and a steeper upward trend in DAZ scores, suggesting accelerated developmental progress – indicative of a potential "catch-up" effect. Panel B shows corresponding data for full-term infants (≥ 37 weeks). Here, the red dashed line represents children of mothers with GDM, and the solid blue line those without. A modest difference in DAZ trajectories is observed between the two groups. While children of mothers with GDM still show slightly elevated rates of development, the differences are less pronounced compared to the preterm group, indicating a weaker effect of GDM on developmental outcomes in full-term births.

Notably, in the preterm group, progress DAZ was not statistically significant across time ($p > 0.05$), whereas it was significant among full-term infants ($p < 0.05$). The main effect of GDM on DAZ reached borderline significance only in the preterm group ($p < 0.1$), suggesting that the adverse impact of GDM on early psychomotor development is more pronounced when combined with prematurity. Furthermore, the interaction term between age and GDM was statistically significant in both gestational age groups ($p < 0.05$). The modeled rate of developmental progression in GDM-exposed preterm infants was more than five times higher than in their full-term counterparts (4.50/0.83 = 5.42), reinforcing the concept of accelerated or "catch-up" development in infants facing the dual burden of prematurity and intrauterine hyperglycemic exposure.

DISCUSSION

This study confirms that children born to mothers with GDM demonstrate an initial delay in psychomotor development, followed by a marked acceleration around the sixth month of life. In contrast, the developmental trajectory of children born to mothers without GDM typically follows a more consistent, exponential curve characterized by steady progress from birth. These findings highlight a unique developmental trajectory in GDM-exposed offspring, marked by early delays and subsequent "catch-up".

Particular attention should be given to preterm infants, as maternal metabolic status during pregnancy is associated with an elevated risk of future developmental

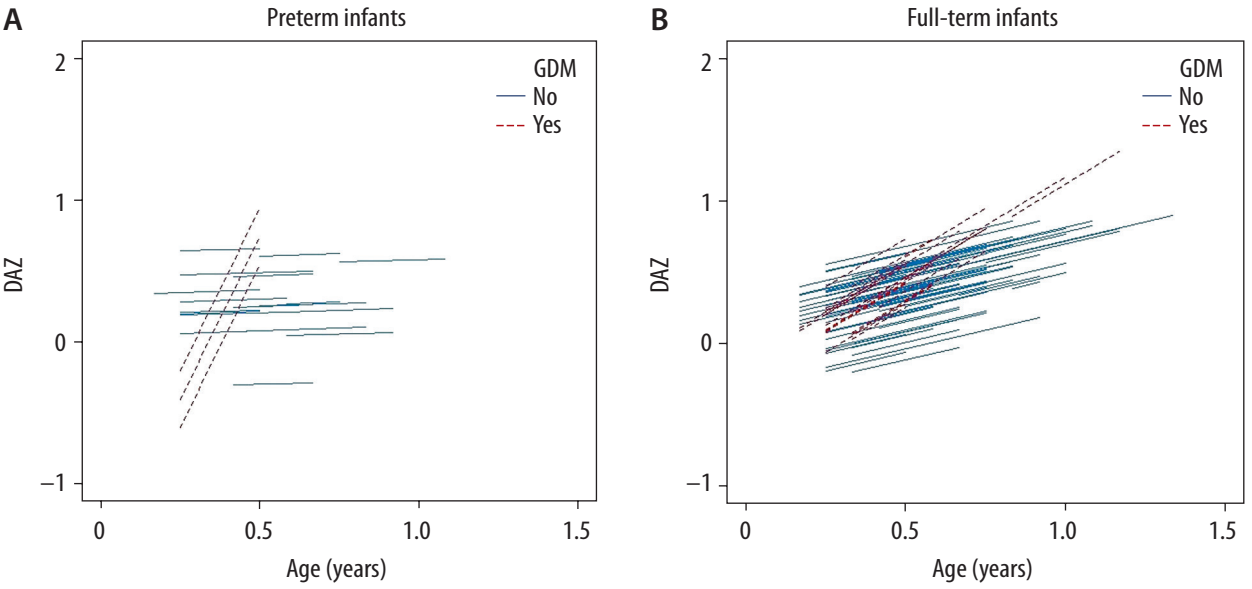

FIGURE 3. Multilevel regression analysis of the development-for-age Z-score, incorporating interaction terms between age and gestational diabetes mellitus, stratified by gestational age

DAZ – development-for-age Z-score, GDM – gestational diabetes mellitus

disorders [17]. The intrauterine environment plays a critical role in shaping the fetus's capacity for metabolic regulation [18, 19]. Importantly, offspring of mothers with GDM are exposed to elevated glucose concentrations in the amniotic fluid even prior to the clinical diagnosis of GDM, potentially contributing to the onset of early metabolic dysregulation in the fetus [20, 21].

The developing organism, particularly during the early stages of prenatal growth, demonstrates a remarkable capacity to adapt to its intrauterine environment. These adaptations can have long-term consequences on postnatal health, consistent with the theory of early metabolic programming [21].

Following birth, hypoglycemia is the most frequently observed complication in newborns of mothers with GDM. The neonate must rapidly adjust to lower glucose levels compared to the elevated concentrations experienced in utero. This metabolic shift requires the activation of endogenous energy reserves and a reorganization of metabolic pathways. These adaptive processes may temporarily impair the child's growth and developmental trajectory [22].

After this initial adjustment period, however, infants born to mothers with GDM often begin to compensate for early deficits through accelerated physical and metabolic development, a process likely driven by intrinsic compensatory mechanisms [23, 24]. This pattern aligns with the observed "catch-up" phenomenon noted in psychomotor development and supports the hypothesis that early-life metabolic stress may set the stage for altered postnatal growth trajectories.

Evidence confirming the adverse effects of maternal diabetes on a child's motor development is supported by the meta-analysis conducted by Arabiat *et al*., which found that children exposed to gestational or pregestational diabetes scored significantly lower in both gross and fine motor skills compared to their non-exposed peers [25]. This effect was especially pronounced among preterm infants and during the early postnatal period. The authors noted that these developmental impairments may be transient, aligning with other studies that suggest compensatory mechanisms may facilitate developmental catch-up in later stages of life. The findings of Arabiat *et al*. also underscore the importance of early monitoring and targeted interventions to support psychomotor development in children exposed to intrauterine hyperglycemia [25].

Similar conclusions were drawn in a recent study by Qian *et al*., which evaluated the neurodevelopment of late preterm infants at a corrected age of 12 months [26]. The study revealed that preterm infants born to mothers with GDM scored significantly lower on standardized cognitive and motor development assessments compared to preterm infants in the control group. These findings further emphasize the necessity of early developmental screening and intervention for this particularly vulnerable population. The negative effects of GDM exposure extend beyond motor functions and affect cognitive development as well. In a systematic review and meta-analysis conducted by Camprubi Robles *et al*., it was shown that children of mothers with diabetes during pregnancy – regardless of the type –achieve lower scores in cognitive abilities such as attention, working memory, and verbal reasoning. This effect was more pronounced in cases of uncontrolled GDM and also among boys, suggesting a potential sex-dependent vulnerability [27].

Comparable findings were reported in a recent study by Liu *et al*., which examined the association between GDM and the risk of neurodevelopmental disorders – including autism spectrum disorder (ASD), attention-deficit/hyperactivity disorder (ADHD), and speech delay – while accounting for race and ethnicity [28]. The study found that the risk of these disorders may be significantly higher among children from minority populations, emphasizing the importance of incorporating socio-demographic factors into the planning of perinatal care and early intervention strategies.

The present study is among the few to investigate developmental differences in children by categorizing them according to gestational age (full-term vs. preterm) and utilizing the GSED to assess multidimensional development. The use of multilevel modeling enabled precise tracking of DAZ over time, offering valuable insights into the developmental trajectories of children born to mothers with GDM.

The results of this study should be interpreted with caution, considering several limitations. First, the sample size of the preterm group was relatively small, which may have reduced the statistical power of subgroup analyses. Second, direct data on neonatal glucose and insulin levels were unavailable, limiting the ability to explore underlying metabolic mechanisms in detail. Furthermore, the absence of information on infant feeding practices – including breastfeeding and dietary patterns – constrains the interpretation of nutritional influences on subsequent development.

The initial developmental delay observed in offspring of mothers with gestational diabetes may be attributed to fetal hyperinsulinemia, a result of excessive intrauterine glucose exposure. Following birth, low levels of insulin-like growth factor 1 (IGF-1) may impair anabolic processes, contributing to early growth restriction and delayed psychomotor development. However, as IGF-1 levels increase and metabolic homeostasis improves in the postnatal period, an acceleration in development often occurs – supporting the hypothesis of compensatory growth in GDM-exposed infants. These findings are consistent with previous studies emphasizing the critical role of IGF-1 in regulating growth and development in children prenatally exposed to maternal hyperglycemia [24, 29].

In addition, the observed developmental pattern may reflect adaptive metabolic and hormonal changes shaped by the fetal environment. Emerging evidence also under-

scores the importance of early-life nutrition in modulating the long-term consequences of metabolic programming, suggesting that targeted dietary interventions could help mitigate adverse outcomes in children of mothers with GDM [30, 31].

CONCLUSIONS

Offspring of mothers with GDM appear to follow a distinct psychomotor developmental trajectory characterized by an initial delay, followed by a period of catch-up development. This compensatory acceleration is likely driven by complex interactions between hormonal, metabolic, and environmental factors.

These findings highlight the importance of early monitoring, tailored developmental support, and nutritional guidance – particularly in preterm infants – to help optimize long-term outcomes in children exposed to gestational diabetes. They also underscore the potential of nutritional interventions to positively influence developmental outcomes and support "catch-up" growth in this vulnerable population.

DISCLOSURES

1. Institutional review board statement: This retrospective study was conducted in accordance with the principles of the Declaration of Helsinki (1964, and its later amendments). According to the statement issued by the Bioethics Committee of the University of Opole (Ref. No. 83800.0052.23.2025), the study did not require approval from the bioethics committee. All data used in the analysis were obtained from existing medical records, anonymized prior to use, and handled in compliance with relevant institutional guidelines and ethical standards.
2. Assistance with the article: The authors would like to thank the two anonymous referees/reviewers for many constructive comments on an earlier draft.
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4. Conflicts of interest: None.

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