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An association between maternal childhood traumatic stress and the development of selected biological and behavioral traits of the infant during the first year of life

Związek pomiędzy traumatycznym stresem matki z okresu dzieciństwa a rozwojem wybranych cech biologicznych i behawioralnych niemowlęcia w pierwszym roku życia

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I would like to thank Dr hab. Anna Ziomkiewicz-Wichary, my supervisor, for her mentoring, motivation, scientific support, and warmth.

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1. Streszczenie

Szacuje się, że co najmniej 20% populacji doświadczyło w okresie dzieciństwa stresu traumatycznego. Za stres traumatyczny można uznać sytuacje, które doprowadzają do nagłej utraty lub ryzyka utraty zasobów osobistych. W odpowiedzi na takie zagrożenie będzie pojawiać się reakcja fizjologiczna i psychologiczna organizmu, a jego następstwa można obserwować również u ich potomków. Nieliczna literatura wskazuje, że wyższy stres traumatyczny matki w dzieciństwie zwiększa ryzyko przedwczesnego porodu oraz niższej masy urodzeniowej dziecka. Nadal jednak brakuje badań podłużnych, które śledziłyby efekty działania stresu traumatycznego z dzieciństwa matki na biologiczne i psychologiczne aspekty rozwoju jej dziecka w sposób długofalowy.

Celem niniejszego zbioru prac było zbadanie związku pomiędzy stresem traumatycznym matki z okresu dzieciństwa a rozwojem biologicznym i psychologicznym jej dziecka w pierwszym roku życia.

Grupę badawczą stanowiły 103 diady, złożone z matki i dziecka. Kobiety były rekrutowane do badania w momencie gdy ich niemowlęta miały około 5 miesięcy, a do kolejnego etapu zapraszano je gdy dzieci osiągnęły 12 miesiąc życia. Do badań włączano zdrowe kobiety, które zarówno w trakcie ciąży jak i laktacji nie paliły papierosów ani nie spożywały alkoholu. Ich ciąża musiała być pojedyncza i przebiegać prawidłowo, a dzieci urodzone w jej wyniku musiały mieć prawidłową masę ciała i być karmione wyłącznie piersią do co najmniej 5 miesiąca życia.

W celu oszacowania poziomu stresu traumatycznego matki z dzieciństwa wykorzystano Kwestionariusz Stresu z Dzieciństwa (ang. Early Life Stress). Następnie na podstawie mediany wyników z niniejszego kwestionariusza podzielono próbę badawczą na dwie grupy złożone z matek z wysokim (powyżej 2 wydarzeń) i niskim (do 2 wydarzeń) poziomem stresu traumatycznego z dzieciństwa. Natomiast w celu określenia temperamentu niemowląt, w 12 miesiącu życia, zastosowano polską adaptację Zrewidowanego Kwestionariusza Zachowań Niemowlęcych (ang. Revised Infant Behaviour Questionnaire). Do oszacowania rozwoju biologicznego wykorzystano dane urodzeniowe zebrane z Książeczek Zdrowia Dziecka oraz wykonano pomiary masy i długości ciała oraz obwodu głowy w 5 i 12 miesiącu życia dziecka. Analizy statystyczne do zweryfikowania hipotez wykonano przy użyciu programu Statistica 12 oraz środowiska R.

W pierwszej pracy z użyciem korelacyjnych modeli St. Nicolaus zbadano relacje pomiędzy stresem traumatycznym matki z dzieciństwa a zestandaryzowanymi rozmiarami ciała w 5 miesiącu życia dziecka oraz czynnikami społecznymi (liczba potomstwa, zadowolenie z sytuacji finansowej i życiowej) i biologicznymi matki (wiek, BMI, WHR, dieta oraz kaloryczność jej mleka). Analizy wykazały istotny i bezpośredni związek pomiędzy stresem traumatycznym matki z dzieciństwa a zestandaryzowanymi pomiarami masy ciała i obwodu głowy.

Natomiast w drugiej pracy z użyciem wielowymiarowych analiz kowariancji (MANCOVA) wykazano istotny związek pomiędzy poziomem stresu traumatycznego z dzieciństwa matki a parametrami rozmiarów ciała dziecka w 5 i 12 miesiącu życia. Jednocześnie nie znaleziono takiego związku z urodzeniowymi rozmiarami ciała. Dodatkowo po wykonaniu jednowymiarowych analiz kowariancji okazało się, że parametrami, które były istotnie związane ze stresem traumatycznym matki z dzieciństwa były masa ciała i obwód głowy. W przypadku dzieci matek , które doświadczyły wyższego stresu traumatycznego w dzieciństwie, zaobserwowano większą masę ciała oraz większy obwód głowy zarówno w 5 jak i 12 miesiącu życia w porównaniu do ich rówieśników, których matki były narażone na niższy stres.

Z kolei ostatnia praca miała na celu zbadanie związku pomiędzy poziomem stresu traumatycznego matki z dzieciństwa a temperamentem niemowlęcia. Zbudowano trzy wielowymiarowe modele kowariancji dla cech temperamentu: surgencja/ ekstrawersja, negatywna afektywność oraz orientacja regulacja. Jednakże nie wykazano istotnego związku pomiędzy stresem traumatycznym matki z okresu dzieciństwa a żadną z badanych cech temperamentalnych niemowlęcia.

Większe rozmiary ciała obserwowane wśród potomstwa kobiet, które doświadczyły wyższego poziomu stresu traumatycznego w dzieciństwie może być adaptacją do trudniejszych warunków środowiska. Jednocześnie brak związku z cechami temperamentalnymi u niemowląt może świadczyć o mniejszej wrażliwości rozwoju cech behawioralnych niż biologicznych.

2. Abstract

Childhood traumatic stress affects at least 20% of the population. Traumatic stress can be defined as any sudden event associated with the loss or threat of loss of resources such as property or even social relationships. The person experiencing traumatic stress has both a physiological and psychological response. Interestingly, the consequences of traumatic stress can be observed even in the next generation. Literature suggests that childhood trauma is associated with a higher risk of premature birth and low birth weight. However, there is a lack of longitudinal studies investigating the relationship between maternal traumatic stress and the development of biological and temperamental traits.

The studies aimed to examine the link between maternal childhood traumatic stress and the development of biological and psychological traits in the first year of life.

The study sample consisted of 103 dyads (mother and infant). The healthy women were recruited when their infants were five months old. The data were collected twice when the children were five and twelve months old. Women who did not smoke cigarettes or drink alcohol during pregnancy and breastfeeding were included in the study. They had a single pregnancy without any complications. Their children were born on time with an appropriate weight for the gestational age and were breastfed for at least five months.

The maternal traumatic childhood stress was estimated using the Early Life Stress Questionnaire. Then, the sample was divided into two groups: women with high and low levels of childhood trauma based on median (Me=2). The infant's temperament was assessed based on the Polish adaptation of the Revised Infant Behavior Questionnaire. Biological development was estimated using anthropometric measurements such as body length, weight, and head circumference at ages 5 and 12 months. Additionally, data about birth outcomes were collected from Health Records. The statistical models were run using Statictica 12 software and the R statistical environment.

In the first paper, we wanted to test the relationship between maternal childhood trauma and infant's standardized measurements of body length, weight, and head circumference, and maternal social and biological factors using St. Nicolaus models that are based on correlation. The analyses have indicated a significant and direct association between maternal childhood trauma, infant's body weight, and head circumference.

In the second paper, we found a significant relationship association between maternal childhood trauma and body size parameters at the age of 5 and 12 months using MANCOVA models. Univariate analyses have investigated that infants of mothers with high childhood trauma characterized higher body weight and bigger head circumference than their peers whose mothers experienced low traumatic stress. There was no relationship between maternal trauma and birth size parameters.

The last paper tested the link between maternal childhood trauma and an infant's temperamental factors, such as surgency/ extraversion, negative affectivity, and orienting regulation. The MANCOVA models found no significant relation between maternal trauma and any of the temperamental factors.

Higher size parameters observed among children with higher maternal childhood trauma might be an adaptation to a challenging environmental condition. Lack of effect in the case of temperamental factors might reflect on the lower vulnerability of psychological development than biological.

3. The list of papers included in the dissertation

I. Apanasewicz, A., Groth, D., Scheffler, C., Hermanussen, M., Piosek, M., Wychowaniec, P., Babiszewska, M., Barbarska, O., & Ziomkiewicz, A. (2020). Traumatized women's infants are bigger than children of mothers without traumas. *Anthropologischer Anzeiger*, 77(5), 359–374.

II. Apanasewicz, A., Danel, D. P., Piosek, M., Wychowaniec, P., Babiszewska-Aksamit, M., & Ziomkiewicz, A. (2022). Maternal childhood trauma is associated with offspring body size during the first year of life. *Scientific Reports*, 12(1), 19619.

III. Apanasewicz, A., Matyas, M., Piosek, M., Jamrozik, N., Winczowska, P., Krzystek-Korpacka, M., Ziomkiewicz, A. Maternal childhood trauma is not associated with breast milk cortisol level and infant temperament at the age of 12 months. (under review *American Journal of Human Biology*).

4. Authors’ declarations of contribution

AUTHORS’ DECLARATIONS OF CONTRIBUTION

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Olga Barbarska (author 8)	• Laboratory analysis of human milk; • Critical comments and help in shaping manuscript.
Anna Ziomkiewicz (author 9)	• Conception of the project “Stress and reproductive function in women - the influence of mother's stress on her breast milk composition, infant temperament and selected biological traits”; • Funding acquisition for the project; • Coordination and supervision of the implementation of the research tasks; • Critical comments and help in shaping manuscript; • Support in improving draft after peer-review.

Olga Barbarska

Załącznik nr 4. Wzór oświadczenia przy składaniu rozprawy doktorskiej w formie spójnego tematycznie zbioru artykułów (w języku angielskim)

10th May 2024

Anna Ziomkiewicz Wichary, PhD

Laboratory of Anthropology

Institute of Zoology and Biomedical Research

Jagiellonian University in Krakow

Declaration

I hereby declare that my contribution to the following manuscript:

Apanasewicz, A., Groth, D., Scheffler, C., Hermanussen, M., Piosek, M., Wychowaniec, P., Babiszewska, M., Barbarska, O., & Ziomkiewicz, A. Traumatized women's infants are bigger than children of mothers without traumas. *Anthropologischer Anzeiger*, 2020, 77(5), 359–374.

is correctly characterized in the table below.

Contributor	Description of main tasks
Anna Apanasewicz (author 1 and corresponding author)	• Review of the literature; • Data collection including anthropology measurements, psychological questionnaire and biology samples; • Formulation of hypothesis; • Design of methods; • Performing the statistic models; • Preparation of result visualization; • Theoretical framework; • Preparation of initial and final draft.
Detlef Groth (autor 2)	• Conception of statistics; • Critical comments and help in shaping manuscript.
Christiane Scheffler (author 3)	• Theoretical framework;

	• Critical comments and help in shaping manuscript.
Michael Hermanussen (author 4)	• Theoretical framework; • Critical comments and help in shaping manuscript.
Magdalena Piosek (author 5)	• Data collection including anthropology measurements, psychological questionnaire and biology samples; • Critical comments and help in shaping manuscript.
Patrycja Wychowaniec (Winczowska) (author 6)	• Data collection including anthropology measurements, psychological questionnaire and biology samples; • Critical comments and help in shaping manuscript.
Magdalena Babiszewska (author 7)	• Support in developing conception of the project "Stress and reproductive function in women - the influence of mother's stress on her breast milk composition, infant temperament and selected biological traits"; • Coordination and supervision of the implementation of the research tasks; • Verification of database; • Critical comments and help in shaping manuscript.
Olga Barbarska (author 8)	• Laboratory analysis of human milk; • Critical comments and help in shaping manuscript.
Anna Ziomkiewicz (author 9)	• Conception of the project "Stress and reproductive function in women - the influence of mother's stress on her breast milk composition, infant temperament and selected biological traits"; • Funding acquisition for the project; • Coordination and supervision of the implementation of the research tasks; • Critical comments and help in shaping manuscript; • Support in improving draft after peer-review.

UDZIAŁ WSPÓŁAUTORÓW W PRACY NAD ARTYKUŁEM

10.05.2024 r.

Mgr Anna Apanasewicz-Grzegorczyk

Zakład Antropologii

Instytut Immunologii i Terapii Doświadczalnej

Polska Akademia Nauk

Oświadczenie

Oświadczam, że mój udział w następującej pracy:

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jest prawidłowo scharakteryzowany w poniższej tabeli.

Autor	Opis udziału własnego
Anna Apanasewicz (autor 1 i korespondencyjny)	• Przegląd literatury • Zbieranie danych psychologicznych, oraz antropologicznych w projekcie; • Opracowanie hipotez postawionych w artykule; • Wybór danych i metod do przetestowania hipotez; • Wykonanie analiz statystycznych; • Opracowanie ram teoretycznych; • Wyciągnięcie wniosków na podstawie uzyskanych wyników; • Napisanie manuskryptu; • Nanoszeniu poprawek w manuskrypcie po recenzjach.
Dariusz Danel (autor 2)	• Koncepcja analiz statystycznych dopasowanych do postawionych hipotez;

	• Przekazanie krytycznych uwag na temat manuskryptu; • Udział w nanoszeniu poprawek w manuskrypcie po recenzjach.
Magdalena Piosek (autor 3)	• Zbieranie danych psychologicznych, oraz antropologicznych w projekcie; • Przekazanie krytycznych uwag na temat manuskryptu.
Patrycja Wychowaniec (Winczowska) (autor 4)	• Zbieranie danych psychologicznych, oraz antropologicznych w projekcie; • Przekazanie krytycznych uwag na temat manuskryptu.
Magdalena Babiszewska-Aksamit (autor 5)	• Udział w formułowaniu koncepcji projektu naukowego „Stres i funkcje reprodukcyjne kobiet - wpływ stresu matki na skład mleka oraz temperament niemowlęcia i jego wybrane cechy biologiczne"; • Koordynacja i monitorowanie pozyskiwania danych w ramach projektu; • Przekazanie krytycznych uwag na temat manuskryptu.
Anna Ziomkiewicz (autor 6)	• Koncepcja projektu naukowego „Stres i funkcje reprodukcyjne kobiet - wpływ stresu matki na skład mleka oraz temperament niemowlęcia i jego wybrane cechy biologiczne"; • Pozyskanie funduszy z Narodowego Centrum Nauki na realizację projektu; • Koordynacja i monitorowanie pozyskiwania danych w ramach projektu; • Przekazanie krytycznych uwag na temat manuskryptu; • Udział w nanoszeniu poprawek w manuskrypcie po recenzjach.

Podpis współautora

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UDZIAŁ WSPÓŁAUTORÓW W PRACY NAD ARTYKUŁEM

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Polska Akademia Nauk

Oświadczenie

Oświadczam, że mój udział w następującej pracy:

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jest prawidłowo scharakteryzowany w poniższej tabeli.

Autor	Opis udziału własnego
Anna Apanasewicz (autor 1 i korespondencyjny)	• Przegląd literatury • Zbieranie danych psychologicznych, oraz antropologicznych w projekcie; • Opracowanie hipotez postawionych w artykule; • Wybór danych i metod do przetestowania hipotez; • Wykonanie analiz statystycznych; • Opracowanie ram teoretycznych; • Wyciągnięcie wniosków na podstawie uzyskanych wyników; • Napisanie manuskryptu; • Nanoszeniu poprawek w manuskrypcie po recenzjach.
Dariusz Danel (autor 2)	• Koncepcja analiz statystycznych dopasowanych do postawionych hipotez;

	• Przekazanie krytycznych uwag na temat manuskryptu; • Udział w nanoszeniu poprawek w manuskrypcie po recenzjach.
Magdalena Piosek (autor 3)	• Zbieranie danych psychologicznych, oraz antropologicznych w projekcie; • Przekazanie krytycznych uwag na temat manuskryptu.
Patrycja Wychowaniec (Winczowska) (autor 4)	• Zbieranie danych psychologicznych, oraz antropologicznych w projekcie; • Przekazanie krytycznych uwag na temat manuskryptu.
Magdalena Babiszewska-Aksamit (autor 5)	• Udział w formułowaniu koncepcji projektu naukowego „Stres i funkcje reprodukcyjne kobiet - wpływ stresu matki na skład mleka oraz temperament niemowlęcia i jego wybrane cechy biologiczne"; • Koordynacja i monitorowanie pozyskiwania danych w ramach projektu; • Przekazanie krytycznych uwag na temat manuskryptu.
Anna Ziomkiewicz (autor 6)	• Koncepcja projektu naukowego „Stres i funkcje reprodukcyjne kobiet - wpływ stresu matki na skład mleka oraz temperament niemowlęcia i jego wybrane cechy biologiczne"; • Pozyskanie funduszy z Narodowego Centrum Nauki na realizację projektu; • Koordynacja i monitorowanie pozyskiwania danych w ramach projektu; • Przekazanie krytycznych uwag na temat manuskryptu; • Udział w nanoszeniu poprawek w manuskrypcie po recenzjach.

Podpis współautora

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Oświadczenie

Oświadczam, że mój udział w następującej pracy:

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jest prawidłowo scharakteryzowany w poniższej tabeli.

Autor	Opis udziału własnego
Anna Apanasewicz (autor 1 i korespondencyjny)	• Przegląd literatury • Zbieranie danych psychologicznych, oraz antropologicznych w projekcie; • Opracowanie hipotez postawionych w artykule; • Wybór danych i metod do przetestowania hipotez; • Wykonanie analiz statystycznych; • Opracowanie ram teoretycznych; • Wyciągnięcie wniosków na podstawie uzyskanych wyników; • Napisanie manuskryptu; • Nanoszeniu poprawek w manuskrypcie po recenzjach.
Dariusz Danel (autor 2)	• Koncepcja analiz statystycznych dopasowanych do postawionych hipotez;

	• Przekazanie krytycznych uwag na temat manuskryptu; • Udział w nanoszeniu poprawek w manuskrypcie po recenzjach.
Magdalena Piosek (autor 3)	• Zbieranie danych psychologicznych, oraz antropologicznych w projekcie; • Przekazanie krytycznych uwag na temat manuskryptu.
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Magdalena Piosek

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Polska Akademia Nauk

Oświadczenie

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Autor	Opis udziału własnego
Anna Apanasewicz (autor 1 i korespondencyjny)	• Przegląd literatury • Zbieranie danych psychologicznych, oraz antropologicznych w projekcie; • Opracowanie hipotez postawionych w artykule; • Wybór danych i metod do przetestowania hipotez; • Wykonanie analiz statystycznych; • Opracowanie ram teoretycznych; • Wyciągnięcie wniosków na podstawie uzyskanych wyników; • Napisanie manuskryptu; • Nanoszeniu poprawek w manuskrypcie po recenzjach.
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Patrycja Winczowska

Podpis współautora

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Dr Magdalena Babiszewska-Aksamit

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Oświadczenie

Oświadczam, że mój udział w następującej pracy:

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Magdalena Babiszewska-Aksamit (autor 5)	• Udział w formułowaniu koncepcji projektu naukowego „Stres i funkcje reprodukcyjne kobiet - wpływ stresu matki na skład mleka oraz temperament niemowlęcia i jego wybrane cechy biologiczne"; • Koordynacja i monitorowanie pozyskiwania danych w ramach projektu; • Przekazanie krytycznych uwag na temat manuskryptu.
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Babiszewska-Aksamit

Podpis współautora

UDZIAŁ WSPÓŁAUTORÓW W PRACY NAD ARTYKUŁEM

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Uniwersytet Jagielloński

Oświadczenie

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Dariusz Danel (autor 2)	• Koncepcja analiz statystycznych dopasowanych do postawionych hipotez;

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Magdalena Babiszewska-Aksamit (autor 5)	• Udział w formułowaniu koncepcji projektu naukowego „Stres i funkcje reprodukcyjne kobiet - wpływ stresu matki na skład mleka oraz temperament niemowlęcia i jego wybrane cechy biologiczne”; • Koordynacja i monitorowanie pozyskiwania danych w ramach projektu; • Przekazanie krytycznych uwag na temat manuskryptu.
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Podpis współautora

UDZIAŁ WSPÓŁAUTORÓW W PRACY NAD ARTYKUŁEM

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Instytut Immunologii i Terapii Doświadczalnej

Polska Akademia Nauki

Oświadczenie

Oświadczam, że mój udział w nieopublikowanym jeszcze manuskrypcie, który został wysłany do American Journal of Human Biology:

Apanasewicz, A., Matyas, M., Piosek, M., Jamrozik, N., Winczowska, P., Krzystek-Korpacka, M., & Ziomkiewicz, A. Maternal childhood trauma is not associated with breast milk cortisol level and infant temperament at the age of 12 months.

jest prawidłowo scharakteryzowany w poniższej tabeli.

Autor	Opis udziału własnego
Anna Apanasewicz (autor 1 i korespondencyjny)	• Przegląd literatury; • Zbieranie danych psychologicznych, antropologicznych oraz próbek biologicznych w projekcie; • Opracowanie hipotez postawionych w artykule; • Wybór danych i metod do przetestowania hipotez; • Koncepcja oraz wykonanie analiz statystycznych; • Opracowanie ram teoretycznych; • Wyciągnięcie wniosków na podstawie uzyskanych wyników; • Napisanie manuskryptu; • Nanoszenie poprawek w manuskrypcie po recenzjach.
Maja Matyas (autor 2)	• Przegląd literatury;

	• Sprawdzanie bazy danych; • Przekazanie krytycznych uwag na temat manuskryptu; • Udział w nanoszeniu poprawek w manuskrypcie po recenzjach.
Magdalena Piosek (autor 3)	• Zbieranie danych psychologicznych, antropologicznych oraz próbek biologicznych w projekcie; • Przekazanie krytycznych uwag na temat manuskryptu.
Natalia Jamrozik (autor 4)	• Wykonywanie analiz laboratoryjnych; • Przekazanie krytycznych uwag na temat manuskryptu
Patrycja Winczowska (autor 5)	• Zbieranie danych psychologicznych, antropologicznych oraz próbek biologicznych w projekcie; • Przekazanie krytycznych uwag na temat manuskryptu.
Małgorzata Krzystek-Korpacka (autor 6)	• Opracowanie metody analiz laboratoryjnych • Wykonywanie analiz laboratoryjnych; • Przekazanie krytycznych uwag na temat manuskryptu.
Anna Ziomkiewicz (autor 7)	• Koncepcja projektu naukowego „Stres i funkcje reprodukcyjne kobiet - wpływ stresu matki na skład mleka oraz temperament niemowlęcia i jego wybrane cechy biologiczne"; • Pozyskanie funduszy z Narodowego Centrum Nauki na realizację projektu; • Koordynacja i monitorowanie pozyskiwania danych w ramach projektu; • Przekazanie krytycznych uwag na temat manuskryptu; • Udział w nanoszeniu poprawek w manuskrypcie po recenzjach.

Podpis współautora

Apanasewicz-Grzeg

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Pracownia Antropologii

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Uniwersytet Jagielloński

Oświadczenie

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5. The first paper

TRAUMATIZED WOMEN'S INFANTS ARE BIGGER THAN CHILDREN OF MOTHERS WITHOUT TRAUMAS

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Traumatized women's infants are bigger than children of mothers without traumas

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With 7 figures and 4 tables

Abstract: Life history theory predicts that experiencing stress during the early period of life will result in accelerated growth and earlier maturation. Indeed, animal and some human studies documented a faster pace of growth in the offspring of stressed mothers. Recent advances in epigenetics suggest that the effects of early developmental stress might be passed across the generations. However, evidence for such intergenerational transmission is scarce, at least in humans. Here we report the results of the study investigating the association between childhood trauma in mothers and physical growth in their children during the first months of life. Anthropometric and psychological data were collected from 99 mothers and their exclusively breastfed children at the age of 5 months. The mothers completed the Early Life Stress Questionnaire to assess childhood trauma. The questionnaire includes questions about the most traumatic events that they had experienced before the age of 12 years. Infant growth was evaluated based on the anthropometric measurements of weight, length, and head circumference. Also, to control for the size of maternal investment, the composition of breast milk samples taken at the time of infant anthropometric measurements was investigated. The children of mothers with higher early life stress tended to have higher weight and bigger head circumference. The association between infant anthropometrics and early maternal stress was not affected by breast milk composition, suggesting that the effect of maternal stress on infant growth was independent of the size of maternal investment. Our results demonstrate that early maternal trauma may affect the pace of growth in the offspring and, in consequence, lead to a faster life history strategy. This effect might be explained via changes in offspring epigenetics.

Keywords: maternal trauma; early life trauma; breastfed infant development; POLS

Introduction

Environmental disturbances occurring during critical periods of prenatal and early postnatal life result in irreversible changes in developmental trajectories that, in the long-term perspective, affect individual health and behavior (Emack et al. 2008; King et al. 2012; Hipwell et al. 2019). Maternal trauma experienced during the prenatal period is inevitably linked with the stress of the fetus and, in most extreme cases, may cause pregnancy termination and result in miscarriage, preterm delivery, and other birth complications (Emack et al. 2008; King et al. 2012). Less extreme forms of maternal stress lead to more subtle changes in fetal physiology that extend beyond the prenatal period and manifest during

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postnatal life. These changes in physiology are the consequence of fetal programming by stress and have a long-term effect on individual health.

Prenatal maternal stress programs offspring responsiveness to stressors via functional modifications in the hypothalamus-pituitary-adrenal axis (HPA axis) (Weinstock 1997; Entringer et al. 2009; Glover et al. 2010). Such modifications frequently result in a heightened response to stressors manifesting by increased cortisol response, higher anxiety, and disturbed social behavior (Weinstock 1997; Entringer et al. 2009). Moreover, stress during pregnancy also affects the mother. In the case of mothers, the stressors increase the reactivity of the HPA axis, usually demonstrating by postnatal depression (O'Mahony et al. 2006; Brummelte & Galea 2010; Stone et al. 2015; Choi et al. 2017). Consequently, maternal behavior and caring for offspring may be affected (Choi et al. 2017).

Furthermore, prenatal stress affects physical growth and development of the offspring. Results of multiple studies demonstrated smaller size at birth and restricted growth during childhood in infants from developing countries who faced environmental stressors during prenatal and the early postnatal period (Nguyen et al. 2014; Bhopal et al. 2019). On the other hand, being small for gestational age as the result of prenatal stress was associated with accelerated development and catch-up growth during the first year of life in infants from western countries who developed in stable postnatal conditions (Albertsson-Wikland & Karlberg 1994; Hokken-Koelega et al. 1995). Despite different results, these observed effects are hypothesized to be associated with epigenetic changes (Burdge et al. 2007; Hocher 2014). Stress during the prenatal period was found to incur epigenetic modifications in genes associated with the activity of the HPA axis (Hocher 2014).

Prenatal maternal stress affects not only the child of the stressed mother but may also affect her grandchild. In this sense, the effect of prenatal stress is transgenerational. Experimental studies in animals demonstrated changes in body size, hormone level, and behavior in offspring of the mothers that experienced stress during their development (Naguib & Gil 2005; Goerlich et al. 2012; Babb et al. 2014; Schmauss et al. 2014). Similar results were demonstrated in very few studies conducted in humans. Mothers who were exposed to trauma during childhood have children with lower height for age, smaller brain size, and higher negative emotionality than their peers born from non-traumatized mothers (Choi et al. 2017; Moog et al. 2018; Hipwell et al. 2019). Simultaneously, traumatized mothers more frequently suffered from postnatal depression and experienced bonding problems with their children (Choi et al. 2017). These results suggest that adverse developmental outcomes in children of traumatized mothers might also arise from changes in maternal care patterns.

Although changes in physical growth and behavior associated with prenatal stress are frequently interpreted as negative due to their grave consequences for the future health, placed in the evolutionary context, these changes suggest adaptive plasticity, which occurs during early human development. Such plasticity allows for developmental response and adaptation to specific cues of the external environment. These coordinated changes in physical growth and behavior might also be explained in the context of Life History Theory and, more specifically, Pace of Life Syndrome (POLS) (Stearn et al. 2008). Theoretical foundations of POLS predict that life history-related traits covary along a dimension of slow versus fast life history. Depending on environmental conditions, humans can adopt slow or fast strategies with different developmental, reproductive, and health outcomes. An individual living in a dangerous and unpredictable environment follows fast life strategy focused on earlier physical and sexual maturation and earlier reproduction due to possible higher risk of mortality at an earlier age (Stearn et al. 2008; Lehmann et al. 2018). In contrast, an individual living in a safe and stable environment follows a slow life strategy with a slower maturation rate and later reproduction. A few studies in humans tested the validity of these predictions with inconclusive results (Tahirović 1998; Chisholm et al. 2005; Lehmann et al. 2018).

Current study

Our study aims to investigate the association between maternal childhood trauma and infant physical development during the first months of life. Apart from prenatal and early postnatal stress discussed above, infant development and health depend on maternal care and breastfeeding. Breast milk not only covers nutritional needs of the infant but also offers protection against pathogens, strengthens the bond between mother and child, and ensure a safe and secure environment for infant development (Mata 1978; Banajeh & Hussein 1999; Walker 2010; Albesharat et al. 2011). Moreover, breast milk was also found to protect against chronic conditions such as obesity via epigenetic changes (Verduci et al. 2014). Hence, it has the potential to countervail the negative effect of prenatal and early postnatal stress.

To our knowledge, none of the published studies investigated how maternal traumatic stressors affect the physical development of a breastfed and well-nourished infant. To fill this gap, we tested the effect of early maternal psychological stressors on growth parameters of 5 months old, exclusively breastfed infants coming from an urban population of healthy and highly educated mothers. Based on theoretical predictions coming from POLS, we hypothesized that early maternal trauma would be associated with faster growth in infants. Furthermore, based on previous research, we hypothesized that this effect would be partially mediated via maternal breastfeeding, namely the energy content of breast milk.

Material and methods

Study group

Data about early childhood maternal stress (traumas) and infant development were collected from 99 Polish mothers and their infants (56 boys and 43 girls) between February 2017 and October 2018. Mothers and their children were included to the study based on the following criteria: for mothers a) age above 18 years old; b) good overall health in particular not suffering from any endocrinological or metabolic disease; c) not smoking and not drinking alcohol; for infants a) born at full gestation (37–42 weeks) from a single and uncomplicated pregnancy; b) appropriate weight for gestational age (not smaller than 2500 g); c) about 5 months old at the time of the study; d) good overall health; e) exclusively breastfed. Each mother signed the written research consent and was informed about the potential risk associated with participation in the study. All of the procedures and questionnaires were reviewed and approved by the Bioethical Committee of Lower Silesian Medical Chamber in Wroclaw.

Maternal childhood trauma

The mothers participating in the study were asked to complete the Early Life Stress Questionnaire. This questionnaire was designed by Sanders & Becker-Lausen in 1995 and validated for the Polish population by Sokołowski & Dragan (2017). The questionnaire includes 19 questions about the most traumatic experience, such as social exclusion, domestic violence, sexual harassment, separation from family, death in family or natural disaster experienced during the period up to 12 years of participants' lives. Being exposed to one of these traumatic experiences scored one point in the questionnaire; thus, overall, the participants could score up to 19 points in the questionnaire.

Anthropometric measurements

Infant body weight was measured using an analog hospital scale with the accuracy to the nearest 0.1 kg and body length using a measuring board (Seca, model 417) with the accuracy to the nearest 0.1 cm. Infant head circumference was measured using measuring tape with accuracy to the nearest 0.1 cm. All of these were further z-scored to adjust for infant age using the WHO reference database. Whereas, the infant birth measures were copied from Health Record. Maternal body height was measured using an anthropometer with the accuracy to the nearest 0.1 cm and body weight using scale (Tanita SC-240 MA) with the accuracy to the nearest 0.1 kg. Based on these measurements, maternal body mass index (BMI) and waist to hip ratio (WHR) were also calculated.

Maternal diet and socioeconomic status

Maternal food intake was assessed based on dietary diary filled in during 3 days within one week. Participants were asked to recall and write down every product they ate or drank (including nutritional supplements) during these 3 days. Subsequently, food intake was recalculated using Dieta 5D software developed and recommended by the Polish National Food and Nutrition Institute to deliver adequate information about the daily intake of energy, protein, carbohydrate, and fat.

Data about maternal education and socioeconomic status were collected using a general questionnaire. The participants were asked to assess their financial and life satisfaction on a 7-grade scale where 1 corresponded to the least satisfying and 7 to the most satisfying status. They were also asked about the total number of born children.

Breast milk samples collection and analysis

The samples of breast milk were collected using an advanced breast milk pump (Medela, model Symphony), which imitates the natural pattern of infant suckling. The samples were collected by mothers during the mid-morning around the time of the second daily feeding episode. Mothers were asked to empty the entire breast, and the collected milk was firmly mixed before aliquoting to the smaller portions. Such a procedure allowed for standardization against the changes in milk composition associated with the time of the day and the stage of the breastfeeding episode (Ruel et al. 1997). We use a sample of 10ml of breast milk portion to assess the energy content of milk using the MIRIS human milk analyzer (MIRIS, Sweden). Each sample was analyzed 3 times, and the average value of these measurements was included as the final result (Cooper et al. 2013).

Statistical analyses

All analysis was conducted using R (version 3.4.3 R Core Team 2017) with supplemental preinstalled packages: openxlsx (Walker 2018), corrplot (Wei & Simko 2017) and igraph (Csardi & Nepusz 2006). St. Nicolas House Analysis (Groth et al. 2019) was used to analyze multiple linear correlations between the investigated variables. Three correlation models were created that included: maternal number of childhood traumas (no_trauma), maternal age (mat_age), maternal BMI (mat_BMI), maternal WHR (mat_WHR), maternal number of children (no_chil), maternal financial satisfaction (sati_money), maternal life satisfaction (sati_life), maternal intake of energy (mat_ener), fat (mat_fat), carbohydrates (mat_carb), protein (mat_prot), energy content of breastmilk (mil_ener), infant birth weight (birth_weight; only in body weight z-score model), birth length (bir_length; only in body length z-score model), birth head circumference (bir_head; only in head circumference z-score model) and z-score of infant body mass (Z-weight), body length (z-leng) and head circumference (Z-head_circu) introduced separately to the models. The associations between the variables were depicted using the correlation matrix graphs, where positive and negative correlations were marked with contrasting colors. Furthermore, these associations were represented using network graphs with the nodes and the edges illustrating variables and connections between them. St. Nicolas House Analysis is a statistical method that allows transforming multiple-variables correlation matrix to graphic model. This analysis is based on the correlation hierarchy, where the determination coefficient informs about the relation between two variables. If these variables correlate directly, their determination coefficient is higher than in the case of variables that correlate indirectly. The algorithm of St. Nicolas House Analysis can link all of the analyzed variables as well as create a few association chains in one model if the variables cannot be linked together. Hence, based on this analysis, direct and indirect correlations between variables could be identified. When edges connected nodes, a direct correlation can be observed. In contrast, indirectly correlated variables were separated by additional nodes. Subsequently, to confirm the structure of the models used in St. Nicolas House Analysis, the same variables were used to run three PCA models with maternal factors and infant anthropometric measurements.

Results

Mothers participating in the study were, on average, 31 years old (maximum age 44.88) and had higher education (over 86% of the mothers had completed college). The average age of their children was five months. Mothers had relatively high financial and life satisfaction. They suffer from, on average, three traumatic stressors during their childhood. Over 60% of the infants were the only child, while less than 40% was a second or third child of their mothers. Women breastfed their infants 11 times per day on average. Table 1 summarizes descriptive statistics for mothers and children from the study.

St. Nicolas House Analysis revealed a significant direct association between infant body length z-score and infant birth length (r = 0.40, $p < 0.001$). Furthermore, the maternal BMI was directly associated with infant birth length (r = 0.33, $p < 0.001$) as well as indirectly and marginally significantly with infant body length z-score (r = 0.17, $p < 0.10$). In addition, maternal BMI was associated with WHR (r = 0.20, $p = 0.05$) and protein intake (r = 0.21, $p = 0.04$).

Table 1. Descriptive statistics of the study group.

	mean	SD
Mothers		
BMI	22.84	3.63
WHR	0.75	0.06
Age [year]	31.09	3.91
Number of childhood traumas	2.81	2.32
Dietary energy intake [kcal]	2195.30	613.06
Dietary protein intake [g]	87.51	27.67
Dietary carbohydrate intake [g]	311.50	107.82
Dietary fat intake [g]	76.61	32.85
Satisfaction from financial situation [score]	5.56	0.93
Life satisfaction [score]	5.73	1.00
Number of breastfeeding episodes [per day]	11.08	2.51
Energy content of breast milk [kcal/100 ml]	71.35	13.04
Infants		
Age [month]	4.76	0.59
Birth weight [g]	3480.96	467.09
Birth length [cm]	54.53	2.85
Birth head circumference [cm]	34.00	1.71
Body weight at age 5 month [g]	7043.53	910.40
Body length at age 5 month [cm]	65.96	3.04
Head circumference at age 5 month [cm]	42.02	1.43
Z-score of body weight	–0.11	1.04
Z-score of body length	0.69	1.41
Z-score of head circumference	0.18	1.02

The energy content of breast milk was not associated with z-score of body length, neither directly nor indirectly. All of the maternal socioeconomic factors were excluded from the model as nonsignificant. Furthermore, there was no association between the z-score of body length and the number of maternal traumas. All associations between maternal variables and infant body length are depicted in Fig. 1, and the structure of these associations is depicted in Fig. 2.

The number of maternal traumatic events was positively and directly associated with infant z-score of body weight ($r = 0.22$, $p = 0.03$). Infant body weight z-score was also significantly and directly associated with infant birth weight ($r = 0.66$, $p < 0.001$) and indirectly (via birth weight) with maternal BMI ($r = 0.25$, $p = 0.01$). Furthermore, maternal BMI was again associated with her WHR ($r = 0.20$, $p = 0.05$) and fat intake ($r = 0.24$, $p = 0.02$). Similarly, as in the case of body length, the energy value of breast milk was not associated with infant body weight z-score. It was also not associated with the number of traumatic events and clustered separately from all other variables analyzed in the study

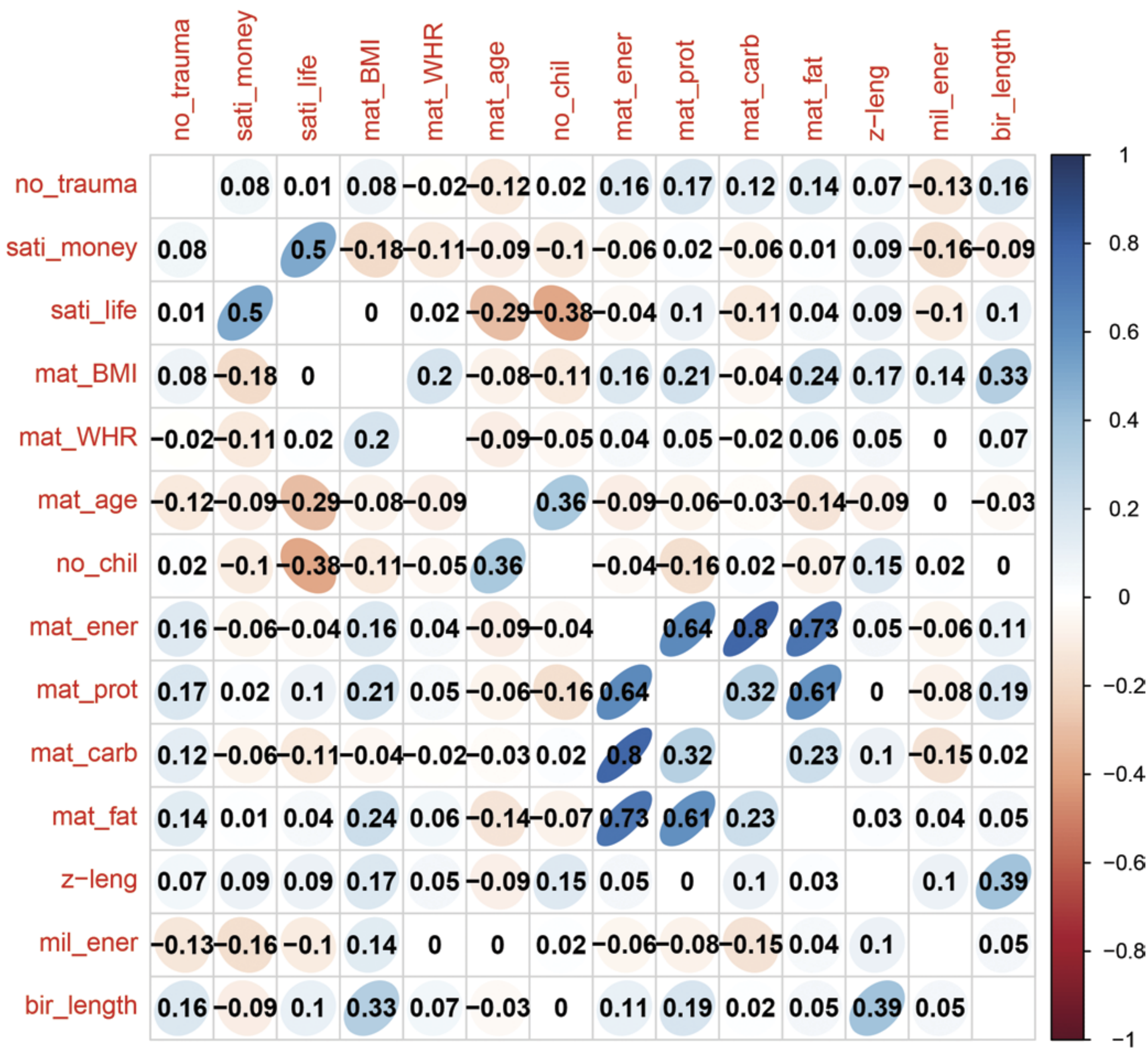

Fig. 1. Correlation matrix for variables: number of traumas (no_trauma), number of children (no_chil), maternal dietary intake of energy (mat_ener), protein (mat_prot) and carbohydrates (mat_carb), energy content of breastmilk (mil_ener), life satisfaction (sati_life) and financial satisfaction (sati_money), maternal BMI (mat_BMI) and WHR (mat_WHR), infant body length z-score (z-leng), and infant body length (bir_length).

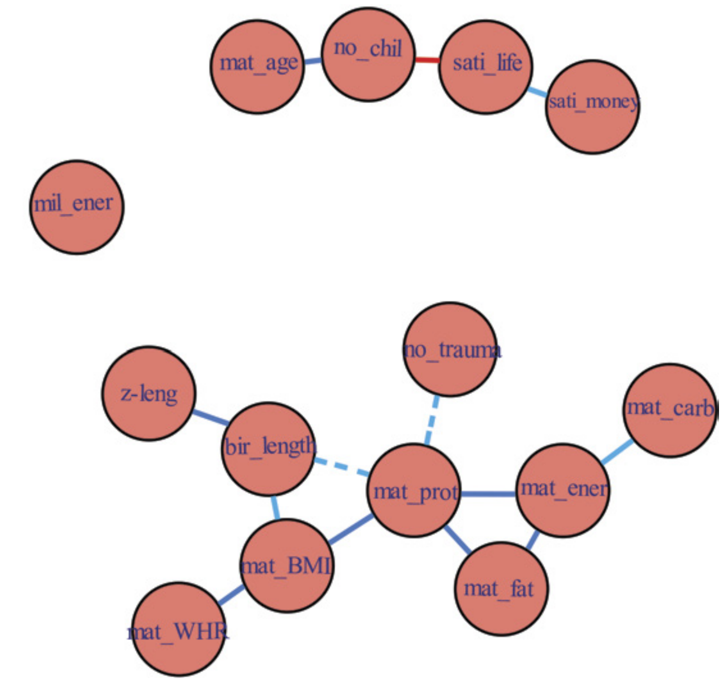

Fig. 2. The structure of the network of the associations between infant body length z-score and maternal factors. Significant, positive correlations are marked blue and negative correlations are marked red. Marginally significant correlations are marked with the dashed line and nonsignificant correlations are marked with gray line.

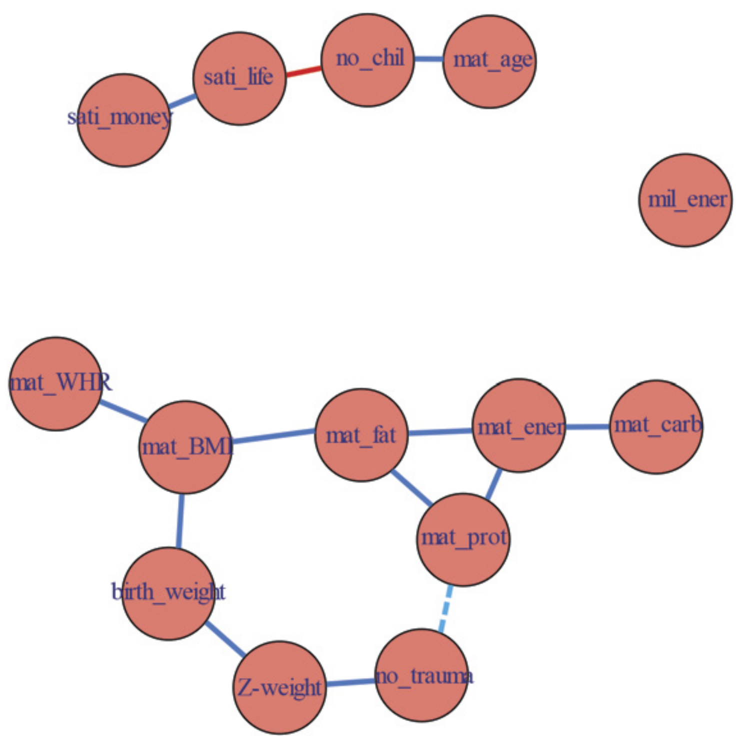

Fig. 3. The structure of the network of the associations between infant body weight z-score and maternal factors. Significant, positive correlations are marked blue and negative correlations are marked red. Marginally significant correlations are marked with the dashed line and nonsignificant correlations are marked with gray line.

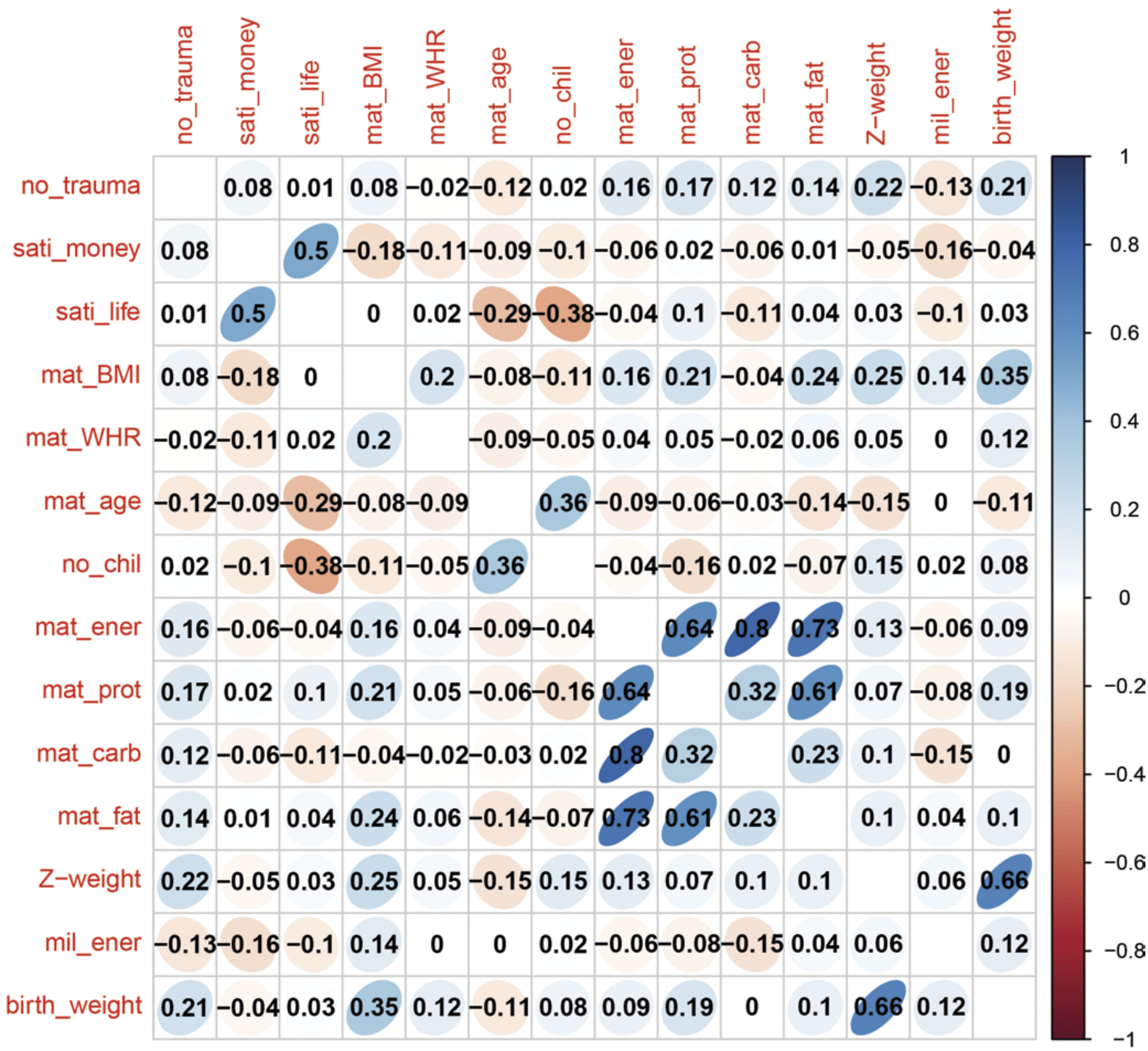

Fig. 4. Correlation matrix for variables: number of traumas (no_trauma), number of children (no_chil), maternal dietary intake of energy (mat_ener), protein (mat_prot) and carbohydrates (mat_carb), energy content of breastmilk (mil_ener), life satisfaction (sati_life) and financial satisfaction (sati_money), maternal BMI (mat_BMI) and WHR (mat_WHR), infant body weight z-score (Z-weight), and infant birth weight (birth_weight).

(Fig. 3). Similarly, maternal socioeconomic factors were excluded from the model as not significant. The matrix of the correlations between variables in the model is presented in Fig. 4.

The number of maternal traumatic events during childhood was positively and directly associated with infant head circumference z-score ($r = 0.26$, $p = 0.01$). Secondly, the z-score of head circumference was also directly associated with infant birth head circumference ($r = 0.43$, $p < 0.001$). The energy content of breast milk was neither associated with infant head circumference nor with the number of maternal traumatic events. It also clustered separately from all other variables analyzed in the study (Fig. 5). An indirect but significant association between maternal BMI and infant head circumference ($r = 0.23$, $p = 0.02$) was also found. Similar to previous models, the maternal socioeconomic variables were excluded as nonsignificant. The matrix of the correlations between variables in the model is presented in Fig. 6.

The Principal Components Analysis, in general, confirmed the results obtained from St. Nicolas House Analysis. The analysis linked together maternal intake of fat, carbohydrate, protein, and energy as the first component (Tables 2–4). The same structure of the associations was observed in St. Nicolas House Analysis graphs (Figs 2, 3, 5). The second

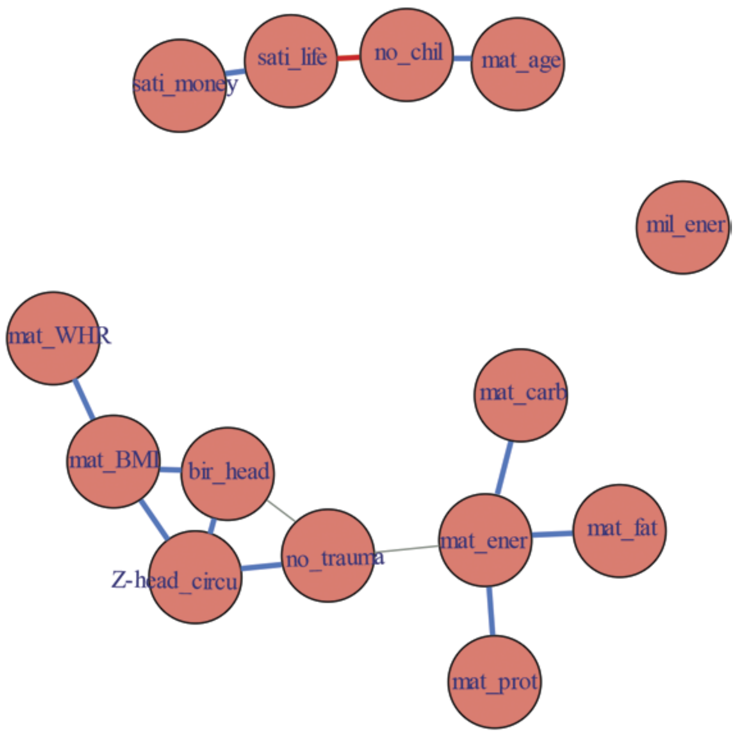

Fig. 5. The structure of the network of the associations between infant head circumference z-score and maternal factors. Significant, positive correlations are marked blue and negative correlations are marked red. Marginally significant correlations are marked with the dashed line and nonsignificant correlations are marked with gray line.

Table 2. The first five principal components from PCA model includes infant body length z-score and maternal factors. A particular variable will be added to identified component, if it has the biggest absolute value for this component. Positive values are marked positive and negative values negative correlation within the identified principal components.

	PC1	PC2	PC3	PC4	PC5
Number of childhood traumas	0.17	0.08	–0.04	0.45	–0.60
Financial satisfaction	–0.05	0.43	0.27	0.35	0.18
Life satisfaction	–0.01	0.60	0.07	0.03	0.17
Maternal BMI	0.18	0.07	–0.56	0.15	–0.17
Maternal WHR	0.09	< –0.001	–0.46	0.13	–0.13
Maternal age	–0.10	–0.42	0.16	0.11	0.04
Number of children	–0.05	–0.48	0.02	0.42	0.13
Dietary energy intake	0.57	–0.08	0.17	–0.06	0.09
Dietary protein intake	0.47	0.06	0.07	–0.09	–0.03
Dietary carbohydrate intake	0.39	–0.15	0.33	0.05	0.12
Dietary fat intake	0.45	0.02	–0.13	–0.17	0.05
Infants' birth length	0.19	0.29	–0.33	0.30	0.09
Infants' body length z-score	0.11	0.05	–0.14	0.59	0.49
Energy content of breast milk	–0.001	–0.07	–0.43	–0.22	0.52
Standard deviation	1.69	1.39	1.33	1.16	1.03
Proportion of variance	0.20	0.14	0.13	0.10	0.08
Cumulative proportion	0.20	0.34	0.47	0.56	0.64

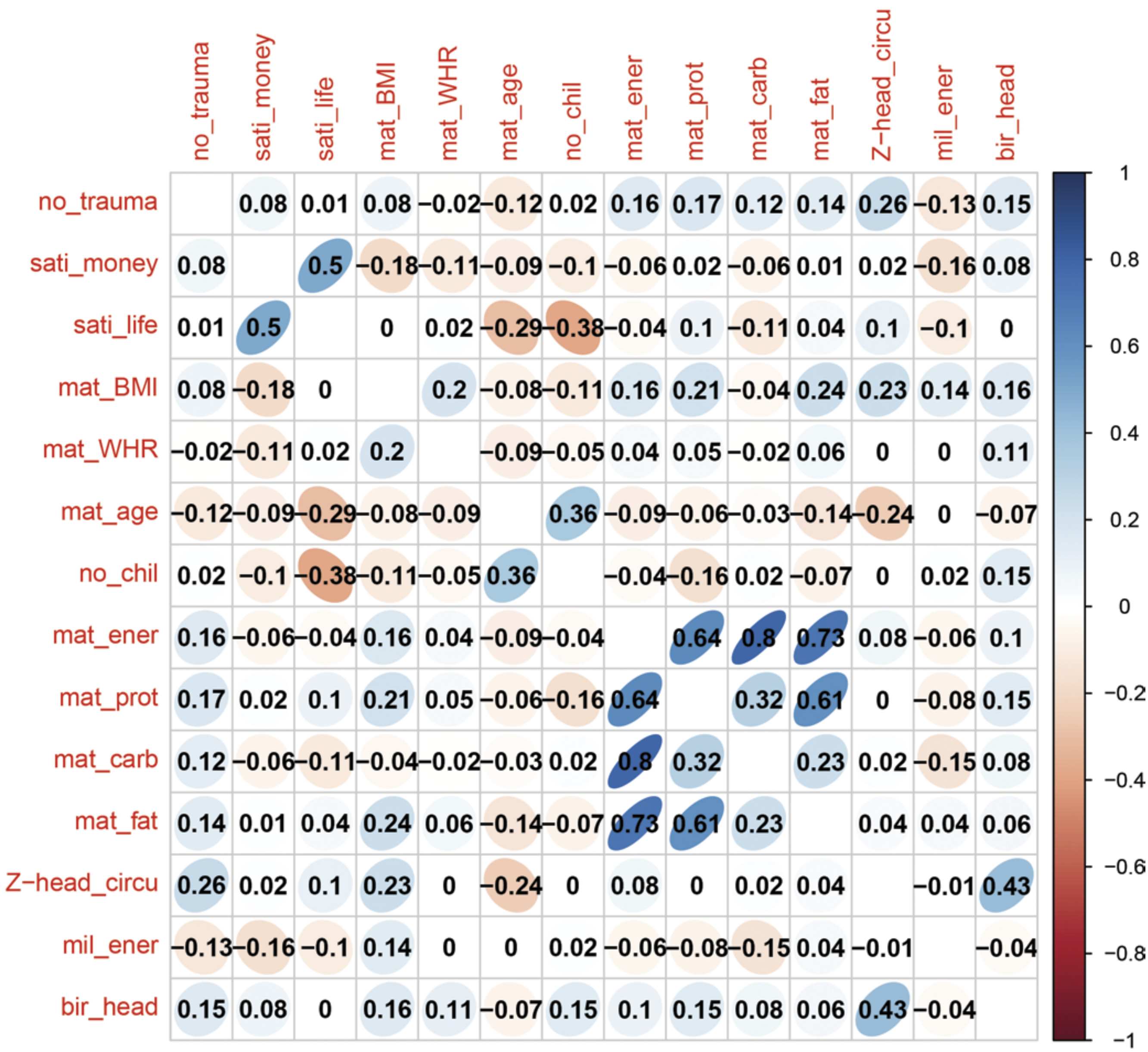

Fig. 6. Correlation matrix for variables: number of traumas (no_trauma), number of children (no_chil), maternal dietary intake of energy (mat_ener), protein (mat_prot) and carbohydrates (mat_carb), energy content of breastmilk (mil_ener), life satisfaction (sati_life) and financial satisfaction (sati_money), maternal BMI (mat_BMI) and WHR (mat_WHR), infant head circumference z-score (Z-head_circu), and infant birth head circumference (bir_head).

component linked together social factors such as life and financial satisfaction, the number of children and maternal age (Tables 2–4), and similar structure of the associations were observed for St. Nicolas House Analysis graphs. The third component linked maternal body characteristics: BMI and WHR, and the same was observed in St. Nicolas House Analysis. Some differences between PCA and St. Nicolas House Analysis were also found. Namely, the number of maternal traumatic events and energy value of milk clustered together in component 4 within all three models of PCA while in St. Nicolas House Analysis energy content of breast milk clustered separately from all other variables analyzed in the study. Also, the infant birth measurements were linked with maternal BMI in all of St. Nicolas House Analysis models.

In contrast, in PCA, each of the birth measurements were built into a different component. The infant birth length was included in component 3 with maternal biological factors. The infant birth weight was placed in component 2 with maternal socioeconomic variables, whereas the infant birth head circumference was incorporated into component 4 with the number of maternal childhood trauma and energy value of milk. Also, a PCA chart (Fig. 7) shows a similar association to matrix correlation (Figs 1, 4, 6).

Table 3. The first five principal components from PCA model includes infant body weight z-score and maternal factors. A particular variable will be added to identified component, if it has the biggest absolute value for this component. Positive values are marked positive and negative values negative correlation within the identified principal components.

	PC1	PC2	PC3	PC4	PC5
Number of maternal childhood traumas	0.19	–0.06	0.12	–0.57	0.20
Satisfaction of money	–0.07	–0.43	–0.20	–0.29	–0.43
Satisfaction of life	–0.02	–0.59	–0.003	–0.03	–0.23
Maternal BMI	0.20	–0.02	0.56	–0.06	–0.19
Maternal WHR	0.10	0.03	0.43	0.02	–0.29
Maternal age	–0.10	0.40	–0.21	–0.02	–0.60
Number of children	–0.02	0.50	–0.03	–0.30	–0.28
Maternal energy intake	0.55	0.04	–0.23	0.11	< 0.001
Maternal protein intake	0.45	–0.10	–0.11	0.11	–0.19
Maternal carbohydrates intake	0.38	0.11	–0.37	–0.04	0.23
Maternal fat intake	0.44	–0.04	0.06	0.24	–0.24
Infants' birth weight	0.29	–0.45	0.02	–0.20	–0.02
Infants' weight z-score	0.24	0.09	0.28	–0.46	0.13
Energy content of breast milk	–0.001	0.09	0.35	0.45	0.07
Standard deviation	1.75	1.40	1.37	1.17	0.99
Proportion of variance	0.22	0.14	0.13	0.09	0.07
Cumulative proportion	0.22	0.36	0.49	0.59	0.66

Table 4. The first five principal components from PCA model includes infant head circumference z-score and maternal factors. A particular variable will be added on identified component, if it has the biggest absolute value for this component. Positive values are marked positive and negative values negative correlation within the identified principal components.

	PC1	PC2	PC3	PC4	PC5
Number of maternal childhood traumas	0.19	0.10	–0.09	0.59	–0.08
Satisfaction of money	–0.06	0.40	0.32	0.14	–0.39
Satisfaction of life	–0.001	0.58	0.14	–0.11	–0.18
Maternal BMI	0.20	0.11	–0.54	–0.06	–0.25
Maternal WHR	0.10	0.02	–0.43	–0.05	–0.39
Maternal age	–0.12	–0.44	0.14	–0.02	–0.52
Number of children	–0.05	–0.47	–0.04	0.31	–0.23
Maternal energy intake	0.55	–0.12	0.19	–0.09	0.04
Maternal protein intake	0.45	0.02	0.12	–0.16	–0.20
Maternal carbohydrates intake	0.38	–0.19	0.32	0.09	0.24
Maternal fat intake	0.44	0.002	–0.08	–0.24	–0.17
Infants' birth head circumference	0.21	0.20	–0.30	0.38	0.10
Infants' head circumference z-score	0.20	0.13	–0.25	0.48	0.30
Energy content of breast milk	–0.004	–0.05	–0.38	–0.42	0.23
Standard deviation	1.71	1.38	1.31	1.19	1.02
Proportion of variance	0.21	0.14	0.12	0.10	0.07
Cumulative proportion	0.21	0.35	0.47	0.57	0.64

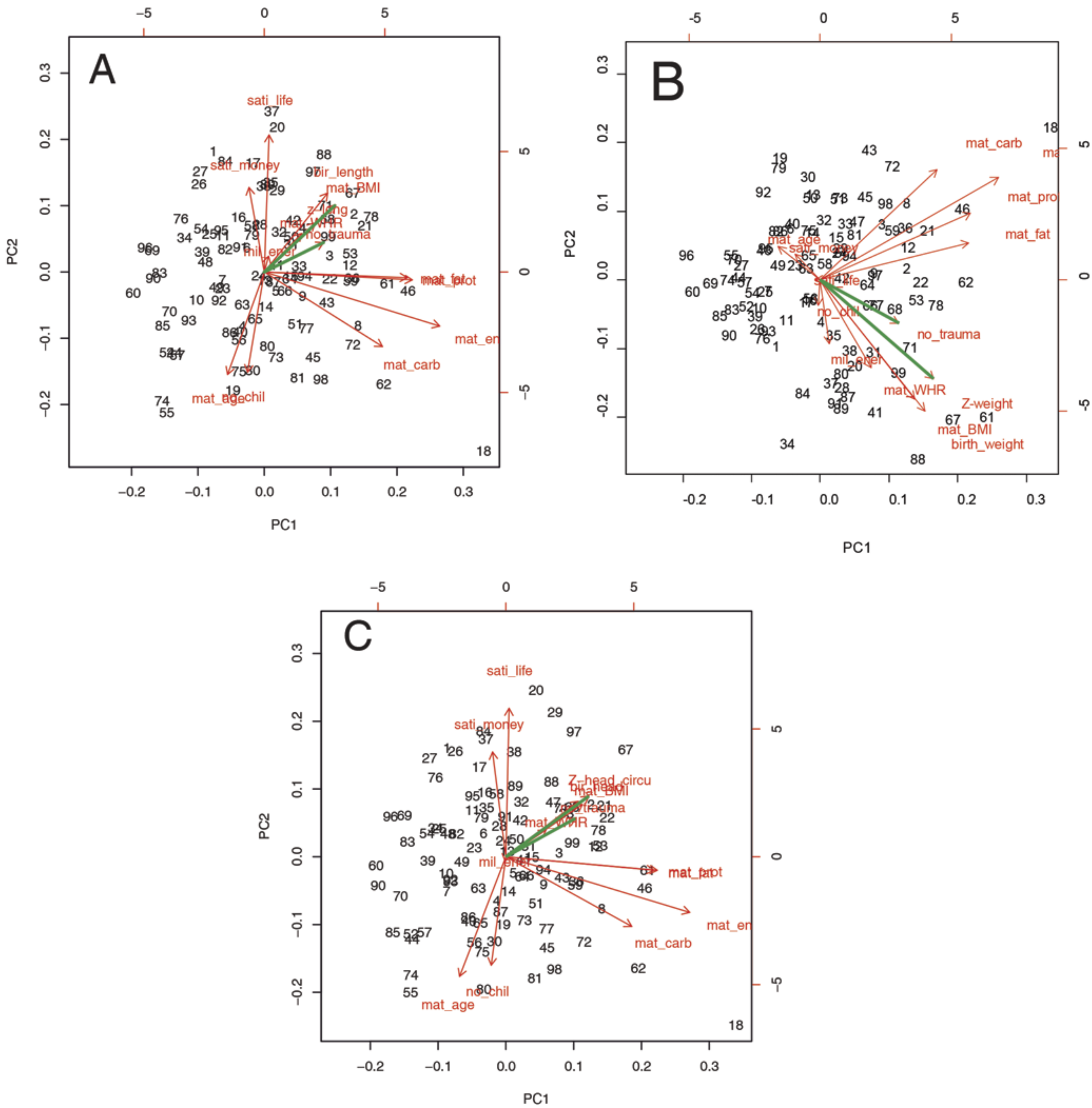

Fig. 7. The PCA charts include maternal factors and infant anthropometric measurements. A green angles were marked association between maternal number of traumas and each of infant z-score parameters: **A.** model for body length; **B.** model for body weight and **C.** model for head circumference. The acute angle symbolizes positive correlation and the obtuse angle symbolizes negative correlation.

Discussion

The results of our study demonstrate a significant association between traumatic stress experienced by mothers and the physical development of their infant. Infants of mothers who experienced more traumatic episodes during childhood had higher body mass and higher head circumference than infants of mothers who experienced fewer traumatic events. The positive direction of this association may suggest that early maternal stress may cause faster growth in body mass and head circumference of their infants.

The results of previous studies depict a slightly different trend. Infants of South African mothers who suffered from early traumatic experiences had decreased physical development. This effect was mediate via maternal postnatal depression associated positively with early maternal trauma and negatively with bonding and maternal care (Choi et al. 2017). Similar results were also observed in infants who experienced traumatic episodes by themselves. For instance, Bhopal et al. (2019) found decelerated physical development during the first year of life in Indian infants who experienced family aggression and violence, maternal death, illness or injuries, or mother-child separation. The same direction of the association, although the different outcome was described in the study by Tahirović (1998) conducted in adolescent girls from Bosnia who suffered traumatic experience associated with war refuge. Girls from this population had a later age of menarche when compared to the control group not affected with refuge trauma.

All of these cited studies were conducted in children from developing countries or countries at war who experienced intensive psychological trauma, physiological stress, and malnutrition. Consequently, their development was slower, possibly due to the inadequate macro- and micronutrient intake and immunological burden. In contrast, our study group consisted of children born to mothers with upper socioeconomic status and higher education. Yet even in such a study group, the exposure to trauma was relatively high (the average number of traumatic experiences was close to 3), and the association with infant growth variables was statistically significant.

Such counterintuitive, at first sight, associations can be explained in the frame of life history strategies and pace-of-life syndrome (POLS) hypothesis. According to this hypothesis, behaviors and environmental conditions that increase the risk of death or predation should be associated with faster life history manifesting in more rapid growth (Wikelski et al. 2003; Dammhahn et al. 2018). Experiencing traumatic events such as domestic violence, sexual harassment, parental loss, or long-term hospitalization during childhood, undoubtedly, might signal an increased risk of early mortality and thus program the organism for faster developmental trajectory. Several recent studies demonstrated that the developmental effect of early trauma is intergenerational so not only mother but also her child can be affected by the impact of severe maternal stress during the childhood (Naguib & Gil 2005; Choi et al. 2017; Moog et al. 2018). Several different mechanisms are postulated for transmission of early trauma including changes in maternal behavior (Penke et al. 2001; Coutellier et al. 2008; Rutherford et al. 2014), placental-fetal stress physiology (Moog et al. 2016; Swales et al. 2018) or epigenetics (Hunter 2012; Nestler 2012). It is thus possible that once the mother was programmed for a faster developmental trajectory, she would pass the same to her child. Examples of POL syndrome in terms of human physical development mainly come from the period of maturation. Existing studies demonstrated faster maturation in boys and girls with higher health-related risk-taking behaviors (Lehmann et al. 2018) and higher early childhood stress (Chisholm et al. 2005). Our study demonstrating infant faster growth in body mass and head circumference in association with early maternal trauma may present additional evidence for POLS working in humans.

Another explanation for the observed association between infant growth and maternal traumatic stress would include catch-up growth, which occurs in an infant during the first year of life as a consequence of intrauterine growth restriction (IUGR) and low birth weight (Hack et al. 1996; Cianfarani et al. 1999; Cianfarani et al. 2002; Knops et al. 2005). Being born small-for-gestational-age (SGA) is usually associated with some form of physiologically stressful in-utero conditions (Mitchell et al. 2004; Boggess et al. 2006; Ndirangu et al. 2012; Kozuki et al. 2013; Ko et al. 2014; Kozuki et al. 2015) which may arise from maternal prenatal psychological stress and prenatal depression (Graignic-Philippe et al. 2014; Babu et al. 2020). Thus, birth size parameters were also included in models to control for catch-up growth. The results of the analysis demonstrated a positive association between infant measurements at birth with the corresponding z-scored measurements at the age of 5 months. These results contradict the expected associations that should be observed during the catch-up growth, which in that case, should be negative. Finally, although the genetic predisposition of bigger mothers giving birth to bigger and faster-growing children cannot be wholly ruled out, it seems unlikely in the case of our sample of traumatized mothers. Body size parameters have a significant genetical component (Hirschhorn & Lettre 2009; McEvoy & Visscher 2009; Ignatieva et al. 2016), usually with multigenic control (Hirschhorn & Lettre 2009; McEvoy & Visscher 2009; Ignatieva et al. 2016). If a genetic component was responsible for the observed association between infant size and maternal trauma, we should also expect a relationship between trauma and maternal body size. Such a relationship was not found in our study. However, maternal trauma may contribute to the genetic makeup of the offspring by causing epigenetic changes in several genes directly or indirectly engaged in the process of growth.

Based on existing literature (Berghänel et al. 2017), we expected that maternal investment in the form of breastfeeding would have a significant effect on the dynamics of infant growth; however, we did not find this effect in our study. The energy value of milk was not associated with infant growth parameters at the age of around five months. This may suggest that the effect of maternal trauma is mediated via factors other than simple caloric intake. One such factor might be the fatty acid composition of breast milk. Both medium- and long-chain fatty acids (especially unsaturated) play a significant role in promoting infant growth (Koletzko & Rodriguez-Palmero 1999; Das 2003). Our research shows that maternal prenatal and early postnatal stress may affect the fatty acid composition of breast milk (Ziomkiewicz et al. in press). It is thus possible that early maternal trauma, which sets thresholds of stress responsiveness and increases the activity of HPA (for review see Juruena et al. 2020), may indirectly influence the fatty acid composition of breast milk and shape trajectory of infant growth. Increased stress and changes in milk composition might also be associated with changes in milk and gut microbiota that are also important for the dynamic of infant growth (Albesharat et al. 2011; LaTuga et al. 2014; Gomez-Gallego et al. 2016; Gao et al. 2018).

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6. The second paper

MATERNAL CHILDHOOD TRAUMA IS ASSSOCIATED WITH OFFSPRING BODY SIZE DURING THE FIRST YEAR OF LIFE

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Maternal childhood trauma is associated with offspring body size during the first year of life

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Maternal childhood trauma (MCT) is an important factor affecting offspring size at birth. Whether the effect of MCT persists during the subsequent development remains unclear. We present the results of a semi-longitudinal investigation examining the physical growth of infants born to mothers with high (HCT) and low (LCT) childhood trauma during the first year of life. One hundred healthy mother-infant dyads were included based on following criteria: exclusive breastfeeding, birth on term with appropriate weight for gestational age. MCT was assessed using the Early Life Stress Questionnaire. The weight, length, and head circumference of the infant were taken at birth, 5 and 12 months postpartum. Separate MANCOVA models were run for infant size at each age. We found an association between MCT and infant size at 5 and 12 months. The children of mothers with HCT had higher weight and greater head circumference than the children of mothers with LCT. These results suggest that MCT might contribute to developmental programming of offspring growth during the first year of life. From an evolutionary perspective, the larger size of HCT mother's offspring might represent an adaptation to potentially harsh environmental conditions. This effect might be mediated by epigenetic changes to DNA and altered breast milk composition.

The prenatal period is a crucial stage of individual development with long-term consequences for subsequent well-being and health[1–3]. This period is characterized by increased vulnerability and sensitivity to environmental disruptors that, if persistent, can disrupt prenatal development and result in fetal growth retardation[4]. One of such factors that influence pre- and postnatal development is maternal stress[5].

Studies have shown that the placental mechanisms can protect the fetus against high maternal stress to some extent; however, these mechanisms are insufficient to completely diminish the effect of increased stress[6]. For example, the placental enzyme 11β-hydroxysteroid dehydrogenase, which converts cortisol to its less physiologically active form cortisone[7,8], only does so to a certain extent; therefore, maternal and fetal cortisol levels during high stress periods correlate with each other[8]. The observed effects of maternal stress on the development of offspring include increased reactivity of the hypothalamus–pituitary–adrenal (HPA) axis [9,10], changes in body size and composition at birth and during postnatal life[11,12]. More specifically, a high level of maternal stress during pregnancy has been found to be associated with a lower weight, length, and head circumference at birth in several studies[11–14], however, some authors have shown a positive or nonsignificant effect[15–17].

Interestingly, a new body of evidence suggests that some maternal stressors experienced even before pregnancy might influence the growth and well-being of an offspring[18]. In particular, extreme traumatic stress during childhood can affect the sensitivity of the HPA axis and, consequently, lead to its long-term dysregulation[19,20]. For example, pregnant women who experience traumatic stress during childhood have a higher awaking cortisol response[21,22]. Recent studies investigating the effects of maternal childhood trauma (MCT) suggest that these developmental effects may be transgenerational (transmitted to the offspring). Although most studies have focused on the behavioral and emotional consequences of MCT, some of them suggest that the biological development of the offspring might be also affected[23–25]. For example, MCT, including violence, is associated with preterm birth[26], lower birth weight[24,27] (although this effect is not universal across all studies[28]), lower infant intracranial volume[25], and a higher cephalization index[23].

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Our preliminary results showed that body weight and head circumference are positively associated with increased maternal childhood trauma among exclusively breastfed infants[29]. Simultaneously, the study also suggested that neither catch-up growth nor breast milk energy density contributed to the observed growth effects[29]. While MCT-associated changes in infant body size have been detected in the very early stages of development–at birth and early postpartum, it remains unclear whether these changes persist in later stages of development. To address this, we studied body size in relation to the MCT level in the same breastfed infants during the first year of life. We hypothesized that the differences in the growth pattern between infants of mothers with high childhood trauma (HCT) and low childhood trauma (LCT) observed during the initial months would persist further in their development.

Materials and methods

Study group and protocol. The study group consisted of 100 mother-infant dyads from Poland. The recruitment of dyads took place when the babies were about 5 months old and was based on the following inclusion criteria: (a) for mothers: age older than 18 years old; not taking steroid medication, smoking, or drinking alcohol during pregnancy or lactation; without metabolic or congenital diseases (b) for infants: being born from a single and uncomplicated pregnancy; at least 37 weeks of gestation with birth weight at least 2600 g and exclusively breastfed for at least 5 months. The above criteria where established based on the literature indicating that children born prematurely or small for gestational age have a different developmental pattern[30–32], especially during the first year of life. Most of them experience catch-up growth, but some remain consequently smaller[33] during this period. Thus, including prematurely born infants in the study group could potentially confound the results.

The study protocol included two meetings with mothers and infants. The first meeting occurred when the babies were approximately 5 months old. During this meeting, we collected maternal and infant measurements, information on maternal socioeconomic status and life satisfaction, birth outcomes, and postpartum depression. At the second meeting that took place when the children were about 12 months, maternal and infant measurements were collected again. At this point, mothers were also asked about their traumatic experience during childhood. This research protocol was approved by the Bioethical Committee of Lower Silesian Medical Chamber in Wroclaw (protocol code 1/NT/2016 from 10.02.2016).

Each participant in the study received information about the course and purpose of the study, giving informed, written consent to participate in the study in accordance with the tenets of the Declaration of Helsinki. Respondents were allowed to opt out of the study at any stage of the study, and there were no legal or financial consequences for opting out.

Maternal childhood trauma, postpartum depression, and socioeconomic status. The MCT was evaluated using the Polish version of the Early Life Stress Questionnaire (ELSQ)[34], which is an international psychological tool constructed based on the Child Abuse and Trauma Scale[35]. Women were asked to indicate their childhood traumatic events up to the age of 12 years. The questionnaire included 19 events such as peer bullying, domestic violence, sexual harassment, long-term illness, or natural disasters. Each event scored 1 point.

Experiencing symptoms of maternal postnatal depression (maternal PD risk) was evaluated using the Polish version of the Edinburgh Postpartum Depression Scale (EPDS). This 4-point and 10-item questionnaire is a widely used tool in clinical and nonclinical settings[28,36]. Following other studies, including those conducted on Polish samples, the cut-off point for higher risk of postpartum depression was defined by a score value of at least 14[36]. Additionally, the participants were asked to assess their financial satisfaction on a 7-point Likert scale (1- very unsatisfied; 7- very satisfied) and declare their educational status (higher education with at least Bachelor's or nonhigher education).

Anthropometric measurements. Anthropometric measurements of the dyads were taken twice. First, when the infants were approximately five months old and second, at twelve months. Maternal body weight was measured with a Tanita SC-240 MA scale (accuracy of 0.1 kg) and height with a stadiometer (accuracy of 0.1 cm). The mothers also reported their pre-pregnancy body weight. The measurements were used to calculate body mass index (BMI; BMI = body weight [kg]/body height [cm]^2). For infants, measurements included body length using a Seca measuring board (model 417; accuracy of 0.1 cm), weight using an analog hospital scale (with an accuracy of 0.1 kg), and head circumference using a measuring tape (with the accuracy of 0.1 cm). Birth outcomes (gestational age, weight, length, and head circumference) were taken from the child's health record.

Statistical methods. Mothers were divided into LCT or HCT groups according to the median value (Me = 2) of the ELSQ score. Differences in mean values of main study variables between LCT and HCT mothers were tested using t-test. Differences in the number of mothers according to increased depression risk and infant sex between LCT and HCT group was tested using chi^2 test. The association between infant weight, length, head circumference, and maternal childhood trauma was tested using General Linear Models. The separate multivariate analyses of covariance (MANCOVA) models were built for growth parameters at each infant age (at birth, 5 and 12 months) with all size parameters as dependent variables, the level of MCT (low–high), infant sex (boy-girl) and risk of maternal postpartum depression (low–high) as categorical predictors, and maternal BMI and infant age as covariates. Following the MANCOVA models, we also ran separate univariate analyses of covariance (ANCOVA) to test which of the dependent variables were statistically significant. In addition, Cohens' d values (group comparisons with different sample size)[37] was calculated to quantify the effect of MCT on infant body size parameters.

Birth outcomes				
	All participants (N = 95) Mean (SD)	HCT (N = 44) Mean (SD)	LCT (N = 51) Mean (SD)	*p*
ELSQ score	2.73 (2.28)	4.76 (1.88)	1.13 (0.83)	< 0.001*
Maternal age [years]	30.47 (3.82)	29.65 (3.48)	31.18 (3.99)	0.051
Maternal BMI before pregnancy [kg/m^2]	22.73 (3.50)	23.22 (4.06)	22.31 (2.92)	0.211
Infant sex [boys%]	55.79	59.09	52.94	0.547
Gestational age [weeks]	39.92 (1.41)	40.09 (1.51)	39.77 (1.32)	0.264
Infant body length [cm]	54.74 (2.90)	55.07 (2.82)	54.45 (2.96)	0.302
Infant weight [g]	3,506.37 (443.69)	3,569.77 (475.51)	3,451.67 (411.16)	0.197
Infant head circumference [cm]	34.02 (1.72)	34.02 (2.03)	34.02 (1.42)	0.993
Infant age approximately 5 months				
	All participants (N = 100) Mean (SD)	HCT (N = 46) Mean (SD)	LCT (N = 54) Mean (SD)	*p*
Financial satisfaction [7-points scale]	5.49(1.03)	5.54(1.09)	5.44(0.98)	0.676
Education [high %]	94.00	91.30	96.30	0.910
ELSQ score	2.81 (2.32)	4.86 (1.90)	1.16 (0.83)	< 0.001*
Maternal age [years]	31.19 (4.04)	30.13 (3.42)	31.98 (4.36)	0.022*
Maternal BMI [kg/m^2]	23.04 (3.56)	23.49 (4.00)	22.67 (3.13)	0.253
Infant sex [boys %]	57.00	58.70	55.56	0.295
Infant age [months]	4.76 (0.58)	4.71 (0.54)	4.81 (0.61)	0.415
Infant body length [cm]	66.12 (3.04)	66.38 (3.25)	65.89 (2.86)	0.422
Infant weight [g]	7,101.53 (920.02)	7,350.46 (1,001.32)	6,878.13 (786.62)	0.008*
Infant head circumference [cm]	42.08 (1.44)	42.40 (1.50)	41.81 (1.35)	0.044*
Infant age approximately 12 months				
	All participants (N = 95) Mean (SD)	HTC (N = 43) Mean (SD)	LTC (N = 52) Mean (SD)	*p*
ELSQ score	2.81 (2.32)	4.86 (1.90)	1.16 (0.83)	< 0.001*
Maternal age [years]	31.77 (3.62)	31.09 (3.11)	32.32 (3.93)	0.098
Maternal BMI [kg/m^2]	22.15 (3.81)	22.71 (4.36)	21.68 (3.26)	0.191
Infant sex [boys%]	57.89	60.47	55.77	0.645
Infant age [months]	12.36 (0.73)	12.35 (0.84)	12.36 (0.63)	0.972
Infant body length [cm]	76.12 (3.23)	76.76 (3.71)	75.60 (2.70)	0.080
Infant weight [g]	9,514.63 (1,035.09)	9,841.86 (1,025.39)	9,244.04 (971.57)	0.005*
Infant head circumference [cm]	46.00 (1.64)	46.40 (1.50)	45.68 (1.68)	0.028*

Table 1. Maternal and infant characteristics in all, HCT and low LCT participants at child's birth, at 5, and 12 months. Significant differences asterisked.

The Henze-Zirkler test indicated multivariate normality of the dependent variables, and the Box M test confirmed the homogeneity of the variance–covariance matrices. Since the deviations from normality were relatively minor and our sample size was sufficient to obtain robust results (n > 30 in both groups), we followed the standard parametric procedure for the univariate analysis. Statistical analysis was performed using StatSoft STATISTICA (data analysis software system), version 12 (www.statsoft.com), and the R statistical environment (version 3.6.0). The statistical significance level was established at $p < 0.05$, however, we also reported a marginally significant effect at $0.06 > p > 0.05$.

Results

The ELSQ score in the study group ranged from 0 to 11 traumatic events during childhood. 46% (n = 46) of the participants suffered from more than 2 traumatic events up to 12 years of age, while only 14% (n = 14) of the women in the study group did not experience any traumatic events. Therefore, mothers who experienced more than 2 traumas were included in the HCT group. Out of all participating mothers, 14 (14%) had an increased risk of postpartum depression according to the defined cut-off point when their babies were five months old. The results of the chi^2 test indicated that there was no association between the MCT and the risk of postpartum depression. The number of women with an increased risk of postpartum depression did not differ between the LCT and HCT groups ($chi^2 < 0.01$, $p = 0.972$). Furthermore, neither maternal economic satisfaction nor education was associated with MCT (Table 1).

Significant differences between groups in the infant size characteristics (body weight, and head circumference) were found at the age of 5 and 12 months (Table 1). In particular infants of HCT mothers were significantly heavier ($t = -2.71$ $p = 0.008$; $t = -2.91$, $p = 0.005$ at 5 and 12 months respectively) and had larger head circumference

Model	Wilks λ	F	ηp^2	*p*
Growth parameters at birth				
Intercept	0.46	33.86	0.54	< 0.001*
Maternal childhood trauma (LCT-HCT)	0.98	0.64	0.02	0.592
Maternal BMI before pregnancy	0.86	4.91	0.14	0.003*
Maternal PD risk (low–high)	0.99	6.38	0.01	0.187
Gestational age	0.82	6.38	0.18	0.001*
Infant sex	0.94	1.94	0.06	0.129
Growth parameters at 5 months				
Intercept	0.09	313.77	0.91	< 0.001*
Maternal childhood trauma (LCT-HCT)	0.90	3.57	0.10	0.017*
Maternal BMI	0.90	3.56	0.10	0.017*
Maternal PD risk (low–high)	0.99	0.42	0.01	0.736
Infant age	0.78	8.67	0.22	< 0.001*
Infant sex	0.77	9.02	0.23	< 0.001*
Growth parameters at 12 months				
Intercept	0.19	122.89	0.81	< 0.001*
Maternal childhood trauma (LCT-HCT)	0.92	2.61	0.08	0.056
Maternal BMI	0.84	5.42	0.16	0.002*
Maternal PD risk (low–high)	0.93	2.19	0.07	0.095
Infant age	0.72	11.17	0.28	< 0.001*
Infant sex	0.70	12.16	0.30	< 0.001*

Table 2. Results of MANCOVA models for the association between level of maternal childhood trauma (LCT, HCT), maternal BMI, maternal postnatal depression risk infant age, sex, and child growth parameters at birth, at 5, and 12 months. Significant effects asterisked and marginally significant underlined.

than infants of LCT mothers (t = −2.04, $p = 0.044$; t = −2.27, $p = 0.028$ for 5 and 12 months, respectively). No significant differences were found in infant body size at birth and the gestational age. Maternal characteristics also did not differ between the HCT and LCT groups, excluding maternal age when the children were 5 months old (Table 1). This accidental but significant difference in age had no effect on any of the infant size parameters.

The MANCOVA models show, that the differences between LCT and HCT in infant growth characteristics (Wilks λ = 0.90, $F_{(3,92)} = 3.57$, $p = 0.0\ 17$) remained significant at the age of 5 months and marginally significant at the age of 12 months (Wilks λ = 0.92, $F_{(3,87)} = 2.61$, $p = 0.056$) after controlling for maternal BMI and risk of postpartum depression as well as infant sex, and age (Table 2). The effect of MCT on growth parameters at birth was not statistically significant (Wilks λ = 0.98, $F_{(3,87)} = 0.64$, $p = 0.592$).

The results of the univariate analysis did not show a significant effect of maternal trauma at birth (Table3). In contrast, a significant association between the level of MCT and infant weight ($F_{(1,94)} = 8.06$, $p = 0.006$, Cohen's d = 0.53) as well as head circumference ($F_{(1,94)} = 6.17$, $p = 0.015$, Cohen's d = 0.42) was found at 5 months (Table 4 and Fig. 1). Similar effects were observed for both also at 12 months ($F_{(1,89)} = 7.17$, $p = 0.009$, d = 0.60; $F_{(1,89)} = 5.06$, $p = 0.027$, d = 0.45 for weight and head circumference, respectively) (Table 5 and Fig. 1). The effect of MCT on body length at 5 and 12 months was not significant.

Discussion

The current semi-longitudinal study for the first time demonstrates that although maternal childhood trauma does not affect infant size at birth, it is significantly and positively associated with infant size during the first year of life. Mothers with HCT had infants with almost 10% higher weight and 2% greater head circumference than mothers with LCT at the age of 5 and 12 months.

The presented results corroborate the results of an experimental study in hens showing that traumatic stress experienced during early life and puberty is related to earlier hatching of offspring and their increased body weight at the age of one month[38]. In contrast, a human study by Choi et al. [28] has found a negative but indirect association between maternal childhood trauma and infant body size (weight and length) via maternal postpartum depression. Almost 30% of the participants in this study suffered from postpartum depression, which in turn predicted a negative infant development outcome at the age of 12 months[28]. The low prevalence of postpartum depression observed in our study (about 14% of the participants) could be related to a common practice of universal and exclusive breastfeeding among the study participants, which has been previously shown to have beneficial effects on maternal well-being[39] and infant development[40]. Contrasting findings also came from the study by Smith et al.[24], who reported a lower birth weight in infants born to mothers who experienced HCT than those with LCT. The discrepancies in the findings between this and our study could be due to the fact that the former did not control for preterm birth and/or low gestational age, both associated with decreased weight at birth[24].

The higher weight in babies born to HCT mothers observed in our study might be associated with impaired glucose metabolism[41,42] which in the future might result in an increased risk of glucose intolerance and metabolic syndrome. Such effects usually co-occur with overweight and obesity[2,43] and have been previously reported in

Model	F (1,89)	*p*
Body length		
Intercept	7.57	0.007*
Maternal childhood trauma (LCT-HCT)	0.04	0.847
Maternal BMI before pregnancy	10.43	0.002*
Maternal PD risk (low–high)	0.15	0.697
Gestational age	13.54	0.004*
Infant sex	4.42	0.038*
Body weight		
Intercept	3.89	0.052
Maternal childhood trauma (LCT-HCT)	0.15	0.696
Maternal BMI before pregnancy	13.56	< 0.001*
Maternal PD risk (low–high)	0.00	0.993
Gestational age	18.45	< 0.001*
Infant sex	4.45	0.038*
Head circumference		
Intercept	15.16	< 0.001*
Maternal childhood trauma (LCT-HCT)	0.53	0.470
Maternal BMI before pregnancy	7.31	0.001*
Maternal PD risk (low–high)	0.27	0.60
Gestational age	6.47	0.013*
Infant sex	3.20	0.077

Table 3. Results of univariate analysis of MANCOVA models for birth outcomes. Significant effects asterisked.

Model	F (1, 94)	*p*
Body length		
Intercept	293.36	< 0.001*
Maternal childhood trauma (LCT-HCT)	0.69	0.408
Maternal BMI	1.32	0.254
Maternal PD risk (low–high)	0.86	0.355
Infant age	4.77	0.032*
Infant sex	5.35	0.023*
Body weight		
Intercept	13.24	< 0.001*
Maternal childhood trauma (LCT-HCT)	8.06	0.006*
Maternal BMI	8.37	0.005*
Maternal PD risk (low–high)	0.44	0.511
Infant age	10.16	0.002*
Infant sex	12.51	< 0.001*
Head circumference		
Intercept	698.87	< 0.001*
Maternal childhood trauma (LCT-HCT)	6.17	0.015*
Maternal BMI	6.84	0.010*
Maternal PD risk (low–high)	1.00	0.320
Infant age	25.86	< 0.001*
Infant sex	26.16	< 0.001*

Table 4. Results of univariate analysis of MANCOVA models for body parameters at the age of 5 months. Significant effects asterisked.

adult descendants of parents with higher trauma[44]. In addition, higher body weight during infancy is related to the risk of being overweight and obesity during adulthood[45]. Thus, the results of our study suggest that the tendency towards an increased weight among children born to HCT mothers might be long-lasting, and probably result in a higher risk of metabolic conditions in adulthood.

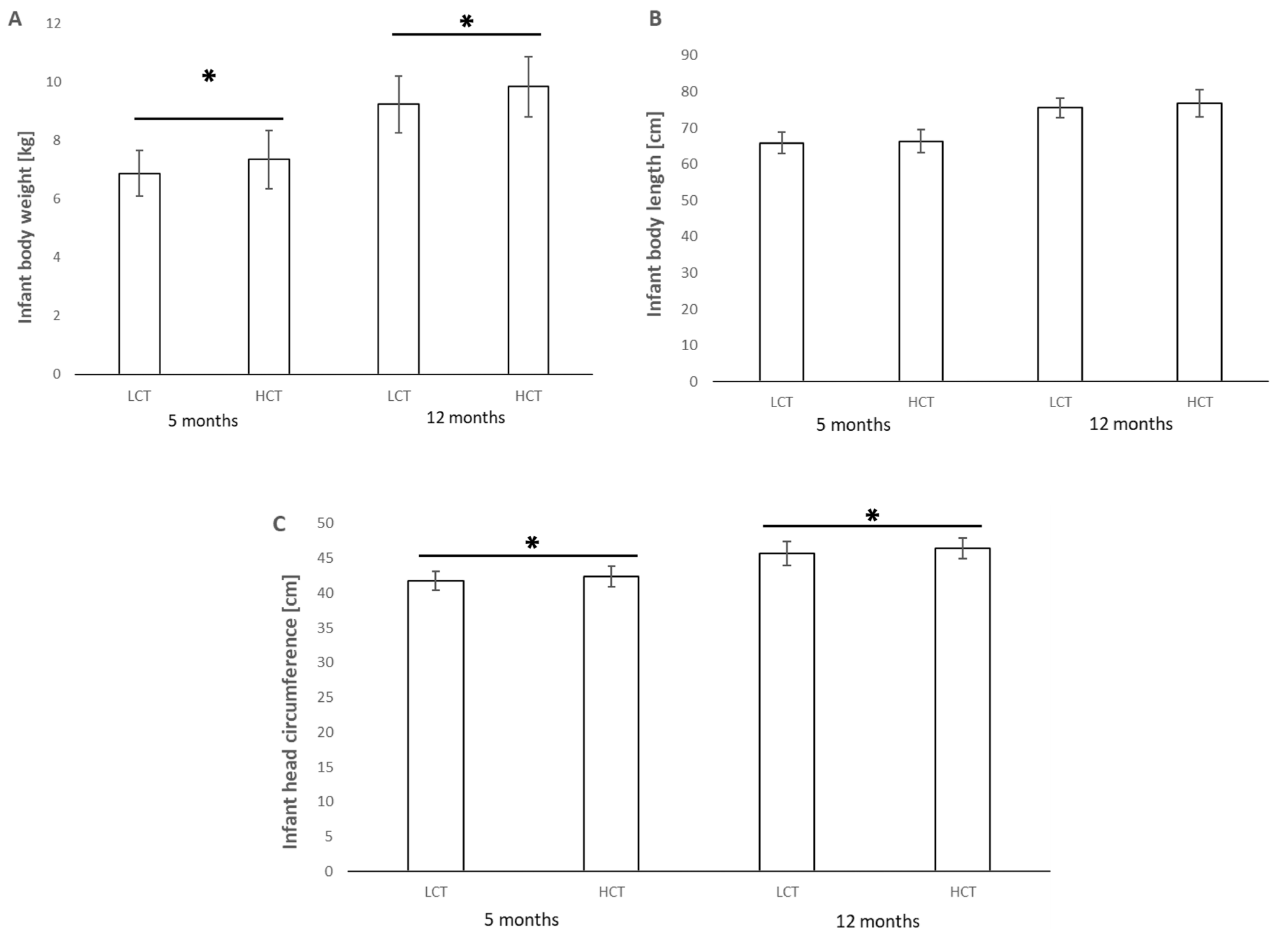

Figure 1. Mean and standard deviations for infant body weight (**A**), length (**B**) and head circumference (**C**) in LCT and HCT mothers at the age of 5, and 12 months. Significant differences asterisked.

Our analysis also showed a larger head circumference among infants of HCT mothers compared to the infant of LCT mothers. This result is in line with a study by Appleton et al.[23], who found that infants born to women with HCT had a higher cephalization index. An increase in the value of this index is usually associated with an increase in head circumference.

Overall, these results suggest that MCT experience may induce intergenerational changes in physical development even without trauma present in the next generation[46]. These effects are hypothesized to be mediated by epigenetic effects on germline and somatic cells, including DNA methylation and histone and RNA modifications[46]. Breast milk, which contains noncoding RNAs, such as microRNAs, serves as epigenetic vectors in molecular communication between mother and offspring and constitutes the first vital gate allowing these developmental effects[46]. Furthermore, HCT may program HPA axis reactivity to produce an increased level of stress hormones, including cortisol, many years after exposition[47]. Thus, cortisol transmitted from serum to breast milk might serve as a second gate[48]. Glucocorticoid levels during the perinatal period demonstrate a long-term programming effect on growth and health during later life[48,49]. Recent literature has shown, that higher values of head circumference and body weight are related to altered levels of fatty acids[50,51] and glucocorticoids[52–54] in breast milk. Additionally, our previous research showed that maternal stress reactivity is positively associated with the level of polyunsaturated fatty acids in milk[55], which are crucial for brain growth and development[56]. It is important to note that the infants in our study group were breastfed exclusively for at least 5 months. Thus, it is possible that maternal HCT was reflected in a modified level of polyunsaturated fatty acids and higher cortisol in milk and, as a result, a faster increase in body mass and head circumference.

From the evolutionary perspective, a larger size of offspring born to HCT mothers might result from a faster life pace, as posited by the Life History Theory. The term Life History was introduced by Stearns in 1992 and emphasizes that environmental conditions can push individuals into two types of life strategies: fast and slow[57]. Individuals that exist under harsh environmental conditions, higher levels of stress and increased risk of mortality must adapt, so such conditions would result in accelerated sexual maturation (e.g., early rapid fat gain) and earlier successful reproduction[58]. On the other hand, it would be associated with significant costs to health and longevity[58,59]. For example, early life adiposity predisposes to obesity and other metabolic disorders in adulthood, while earlier and faster reproduction generates considerable metabolic cost to the individual[60]. According to this theory we postulate that the MCT can be, to some extent, treated as an indicator of a stressful environment and harsh condition within the meaning of the Life History Theory. It is also possible that the observed effect

Model	F (1,89)	p
Body length		
Intercept	79.63	< 0.001*
Maternal childhood trauma (LCT-HCT)	3.09	0.082
Maternal BMI	3.21	0.077
Maternal PD risk (low–high)	5.62	0.020*
Infant age	29.48	< 0.001*
Infant sex	8.73	0.004*
Body weight		
Intercept	0.54	0.466
Maternal childhood trauma (LCT-HCT)	7.17	0.009*
Maternal BMI	15.475	< 0.001*
Maternal PD risk (low–high)	2.88	0.093
Infant age	15.08	< 0.001*
Infant sex	6.38	0.013*
Head circumference		
Intercept	193.36	< 0.001*
Maternal childhood trauma (LCT-HCT)	5.06	0.027*
Maternal BMI	2.23	0.139
Maternal PD risk (low–high)	0.08	0.775
Infant age	14.40	< 0.001*
Infant sex	32.71	< 0.001*

Table 5. Results of univariate analysis of MANCOVA models for body parameters at the age of 12 months. Significant effects asterisked.

may represent a mismatch between maternal and offspring developmental environments, where the maternal adaptive response to a harsh environment might induce long-term changes in offspring development, even in the absence of ecological obstacles.

One of the limitations of our study might be the fact that participants childhood traumatic events retrospectively. However, this limitation is difficult to avoid due to the extended period between maternal childhood and pregnancy. We also did not know how often and for how long women had been exposed to the reported experiences. To minimize the recall bias, we assessed MCT using a standardized psychological questionnaire, which was successfully applied in several other studies[34,61–63]. Furthermore, we did not control for post-traumatic stress disorder (PTSD) and resilience as the additional factors in the analysis. Several studies have underlined the effect of childhood trauma on the prevalence of PTSD[64]. The latter has been shown to have a long-lasting effect on maternal metabolism and as a consequence, on the development and health of the offspring[65]. Whereas resilience is postulated as a protective factor with the potential to decrease the negative effect of childhood trauma on the development of offspring and future health[66]. Finally, the information about birth outcomes was collected from child health records instead of being measured, so the measurement protocol could not have been entirely consistent between different hospitals.

Our study demonstrates that MCT is significantly associated with the size of the offspring during the first year of life even after adjusting for other significant factors that influenced body size such as maternal BMI and postnatal depression, infant age, sex, and age. Children of mothers with HCT had higher weight and larger head circumference than peers born to mothers with LCT, and this effect was independent of body size at birth. These results suggest that MCT might contribute to alterations in the maternal physiology of the HPA axis, which in turn program the development of offspring in the long-term perspective. We propose that this effect may arise from the faster pace of life syndrome mediated by epigenetic changes to DNA and the altered composition of breast milk.

Data availability

The data set analyzed during the current study is available from the corresponding author on request.

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Author contributions
A.A. contributed to the conception and design of the study, collected data, conducted the statistical analysis of data, and drafted the manuscript, D.D. conducted the statistical analysis of data and commented on the manuscript, M.P. and P.W. collected data and commented on the manuscript, M.B.-A. contributed to design of the study and commented on the manuscript, A.Z. contributed to design of the study, supervision, managed the data collection, funding beneficiary, and commented on the manuscript.

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7. The third paper

MATERNAL CHILDHOOD TRAUMA IS NOT ASSOCIATED BREAST MILK CORTISOL LEVEL AND INFANT TEMPERAMENT AT THE AGE OF 12 MONTH

Maternal childhood trauma is not associated with breast milk cortisol level and infant temperament at the age of 12 months

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Abstract

Some studies found that maternal pre-pregnancy traumatic stress might affect children's temperament. For instance, higher maternal childhood trauma (MCT) positively correlates with infant negative affectivity, but the transmission mechanism remains unknown. This study sought to confirm the involvement of milk cortisol in the link between MCT and infant temperament.

The study group included 103 mothers and their infants. MCT was assessed based on the Early Life Stress Questionnaire and infant temperament using the Infant Behavior Questionnaire at 12 months of infant life. Cortisol was assayed in milk samples collected at five months of infant life using the ELISA method. Based on the ELSQ median, the study group was divided into low and high MCT. We calculated correlations to test the association between ELSQ and cortisol. The MANCOVA models were run to check the effect of low vs high MCT on infant temperament.

No association was found between ELSQ and cortisol. Moreover, MCT was unrelated to the infant's temperamental factors.

In light of the results, several explanations are possible. We cannot exclude the possibility that the study group was little affected by traumatic events. Moreover, other factors, such as maternal caregiving or other milk components, could diminish the MCT effect.

Keywords: infant behaviors, trauma transmission, milk composition, milk hormones

Introduction

Early life stress is an essential factor affecting individual health and well-being in the future. Intense negative experiences early in life incur significant and frequently irreversible changes to a child's brain function, behavioral development, and stress reactivity (McKay et al., 2021). A growing body of evidence demonstrates that these negative experiences, collectively known as childhood trauma, dysregulate physiological stress response (Gonzalez et al., 2009; Bowers et al., 2018) causing alterations in both basal and stress-induced cortisol. Early trauma increases the risk of mental problems, for example, anxiety and depression (McKay et al., 2021). Experimental and observational studies suggest that behavioral effects of trauma might be passed to the next generation (Choi et al., 2017; Jawaid et al., 2018). Transmission of trauma effects between generations might be observable even during childhood (Plant et al., 2018). For instance, maternal childhood trauma (MCT) might be associated with child externalizing and internalizing behavior (Grabow et al., 2017), socioemotional difficulties (Choi et al., 2017; Folger et al., 2017), and anxiety (Robinson et al., 2019).

Temperament is a set of behavioral traits determined by genes, environment, maturation, and personal experience. This set of behavioral characteristics is specific to the individual and varies within the population (Rothbart & Derryberry, 1981). Temperamental traits constitute the foundation of personality and regulate individual emotionality, reactivity, and activity (Rothbart & Sheese, 2007). It is postulated that temperament is stable throughout life, with only slight observable changes occurring during infancy and adolescence (Dragan et al., 2011). Longitudinal observations have indicated that temperamental traits emerge non-concurrently at the different stages of life, and their development continues during childhood and adolescence. Some indications of temperamental traits, including negative affectivity, might be observable even during the very first few days of life (Rothbart, 1991).

From an evolutionary perspective, the manifestation of the negative affectivity during the first postnatal days may suggest its high relevance for survival. The trait reflects an infant's reaction in response to negative stimuli. Since the behavioral repertoire of a newborn is limited during this period, crying, in particular, is a significant way to inform parents about potential negative triggers (Newman, 1985). Only later during development, approximately at three months, infants begin to respond to positive stimuli, called surgency/extraversion. They smile, vocalize, and move their limbs in response to positive triggers (Rothbart et al., 1994). Positive reactivity is crucial in the social context and enables forming bonds with the closest carry giver and more distant relatives (Schmidt & Cohn, 2001). Orienting/regulation includes all behaviors related to self-soothing by thumb-sucking and calming in response to parent methods (Rothbart, 1991). The dynamic development of the child during the first year of life, including motor skills, is reflected in the dynamic occurrence of consecutive temperamental traits and subtle modifications in their manifestation (Rothbart, 1989).

Prenatal stress is one of the environmental factors that can impact infant temperament, for example (Graignic-Philippe et al., 2014). In one study, exposition to prenatal stress related to natural disasters was associated with a higher level of activity and a lower level of high intensity to pleasure, approach, and fearfulness (Zhang et al., 2018). In another, maternal distress during pregnancy was associated with negative reactivity (positively), fearfulness (positively), and falling reactivity (negatively) (Nolvi et al., 2016). It's interesting to note that experiencing high levels of stress during the pre-pregnancy period may be linked to the child's temperament during their early years (Enlow et al., 2017; Folger et al., 2017). For instance, MCT can increase the risk of children’s negative affectivity and decrease self-regulation (Bouvette-Turcot et al., 2020; Choi et al., 2017).

Recent research identifies potential factors associated with the transmission of maternal trauma to the next generation. MCT and child temperament are linked via several psychological factors. It was proposed that MCT affects infant temperament by increasing the risk of maternal postpartum depression and impairing mother-infant attachment (Choi et al., 2017). These psychological factors are deeply rooted in biological mechanisms. For instance, depression is known to decrease maternal levels of oxytocin (Scatliffe et al., 2019), the hormone that supports and regulates mother-infant interaction (Strathearn et al., 2012). Furthermore, chronic maternal stress during childhood dysregulates HPA cortisol response (Bowers et al., 2018), and children who were prenatally exposed to high levels of cortisol had higher levels of emotional reactivity, activity (de Weerth et al., 2003), and negative affectivity (Davis et al., 2007). Also, children of mothers who experienced higher lifetime trauma and were prenatally exposed to increased cortisol had higher distress to limitation than their peers with the same level of maternal trauma but less exposition to cortisol (Enlow et al., 2017).

Cortisol can be transferred from mother to child both prenatally and postnatally. Levels of cortisol in maternal serum reflect those in milk during lactation (Grey et al., 2013). Breastfed infants of mothers with higher salivary cortisol tended to be more anxious (Glynn et al., 2007) but see(Mohd Shukri et al., 2019). Moreover, a higher milk cortisol was positively related to infant negative affectivity(Grey et al., 2013) and fear (Nolvi et al., 2018). However, Hechler et al. (2018) found no association between infant crying and milk cortisol. Also, glucocorticoid circadian changes in milk were not related to infant behavior at three months (Toorop et al., 2020).

To our knowledge, none of the studies have analyzed if maternal milk cortisol is involved in a relationship between MCT and infant temperament. To fill this gap, we studied the association between MCT, milk cortisol, and temperament in 12-month-old infants exclusively breastfed for at least five months. We hypothesized that infants of mothers with high MCT would characterize higher levels of negative affectivity and activity. Also, we hypothesized that these differences in temperament might arise from distinct milk cortisol levels in mothers with lower and higher MCT during exclusive breastfeeding.

Materials and methods

The study group consisted of healthy women and infants without congenital or chronic diseases who participated in Mum's Milk Study (Ziomkiewicz et al., 2021). Dyads were included based on the following criteria: for the infant - a) being born at least 37 weeks of gestation; b) from singleton, uncomplicated pregnancy; c) with a birth weight of at least 2500 g, d) exclusively breastfed for at least five months of life; for mothers - a) being at least 18 years old, b) not drinking alcohol or smoking cigarettes during pregnancy and lactation.

Mothers were informed about the study's course and purpose. They provided written consent for themselves and their children. The Bioethical Committee of the Lower Silesian Medical Chamber in Wroclaw approved all study procedures (approval identification number 1/NT/2016 from 10.02.2016).

We collected completed data from 103 mothers. However, we identified and excluded one outlier based on the infant's temperamental trait of vocal reactivity. Hence, the sample in the study included 102 mother–infant dyads (57% boys).

Participating women were invited twice for study meetings. The first meeting was scheduled when the children were around five, while the second was when they were 12 months old. During the first meeting, mothers collected single milk samples and were asked to fill in a general questionnaire and the Edinburgh Postpartum Depression Scale. During the second meeting, mothers filled in the Revised Infant Behavior Questionnaire and the Early Life Stress Questionnaire.

Questionnaires

The general questionnaire collected information about maternal demographics, education, infant sex, age, health condition, and birth outcomes. The Polish adaptation of the Early Life Stress Questionnaire (EPDS) (Kossakowska, 2013) was used to assess maternal risk of postpartum depression. This 4-points per 10-item survey (Cox et al., 1987) is commonly used and implemented in clinical and non-clinical studies (Choi et al., 2017).

The Polish version of the Early Life Stress Questionnaire (ELSQ) (Sokołowski & Dragan, 2017) led to the assessment of the intensity of maternal early life stress (maternal childhood trauma). This questionnaire was based on a list of the most extreme life stress events (Sanders & Becker-Lausen, 1995). The Polish version includes 19 questions about the experiences such as peers' rejection, sexual abuse, natural disaster, and separation or death of a parent or sibling) up to 12 years old (Sokołowski & Dragan, 2017).

The mothers assessed infant temperament at twelve months based on the Polish version of the Revised Infant Behavior Questionnaire (IBQ-R) (Dragan et al., 2011; Gartstein & Rothbart, 2003). The questionnaire describes 14 traits and three main factors of infant temperament (Tab.1) (Dragan et al., 2011).

Tabel 1. Definition of each of 14 temperamental traits (Gartstein & Rothbart, 2003) and division of temperamental traits into three main factors of infant temperament: surgency/extraversion, negative affectivity, and orienting regulation (Dragan et al., 2011).

Surgency/ extraversion	Negative affectivity	Orienting regulation
Approach- rapid closing and positive reaction to pleasurable activities	**Activity level**- significant movement of limbs including squirming	**Perceptual sensitivity**- sighting the very low-intensity external stimulants
Vocal reactivity- intentional producing the positive sounds by the child during diverse activity	**Sadness**- lower mood and activity	**Low-intensity pleasure**- enjoying and pleasure which is linked with low-intensity stimuli
High-intensity pleasure– enjoying and pleasure which is linked with high-intensity stimuli	**Distress to limitation**- negative reaction (crying, fussing) in response to being unable to do the desired activity	**Duration of orienting**- long-lasting attention to only one object
Smiling & laughter- smiling and laughter during playing and daily activities	**Fear**- startle or distress in response to sudden changes or new thing	
Cuddliness- positive reaction and pleasure in response to huge by caregivers	**Falling reactivity**- the pace of calming after distress, exciting or other type of arousal	
Soothability- decreasing of negative expression (crying, fussing) in response to calm technics		

Breast milk collection and cortisol level analysis

The participants collected milk samples using the Medela Symphony medical breast pump (Medela AG, Switzerland) available at the laboratory (Ziomkiewicz et al., 2021). Immediately after collection, the samples were divided into small portions and frozen at -80° C for future analyses.

Milk samples were centrifuged (12,500×g, 4°C for 10 min) to receive skim milk. Clear milk serum was then collected and re-centrifuged to assess cortisol levels. Cortisol levels were analyzed using the Salivary Cortisol Inhibitor ELISA Kit (SLV-4635, DRG Instruments GmbH, Germany) according to manufacturer procedure. The concentration was measured using the colorimetric method with Infinite M200 plate spectrophotometer (Tecan Group Ltd., Männedorf, Switzerland) at 450 nm. The mean intra-assay coefficient of variation was 6.81%, while inter-assay was 6.48%.

Statistics

Data from participating mothers were divided into two groups (low and high maternal childhood trauma) based on the median value (Me=2) of ELSQ. Differences in maternal age, and infant behavioral traits between groups by t-test, in financial satisfaction and EPDS score by U-Mann-Whitney test, whereas in infant sex and maternal education by chi-square test.

The association between infant temperament and maternal childhood trauma was tested using General Linear Models. The separate multivariate analyses of covariance (MANCOVA) models were built for each main scale of infant temperament (surgency/extraversion, negative affectivity, and orienting regulation) according to Dragan (2011) (Tab.1) as dependent variables, the level of MCT (low-high) as a categorical predictor, maternal EPDS score as continuous variable. Following the MANCOVA models, we also ran separate univariate analyses of covariance (ANCOVA) to test which of the dependent variables were statistically significant. The statistical models were performed using StatSoft STATISTICA (data analysis software system), version 12 (www.statsoft.com). The statistical significance was established at $p<0.05$.

Results

The average age of mothers was 31.7 years old. Most (96 %) had higher education and relatively high financial satisfaction (mean 5.5 on a 7-point scale). Most of the mothers (88%) still breastfed their children at the age of 12 months, 9 finished breastfeeding after five months, and three did not provide information regarding breastfeeding. The mean gestational age for children was 39.8 weeks, and the mean birth weight was 3000.5 g. Information about infant temperament and other characteristics is presented in Table 2.

Table 2. Maternal and infant characteristics in all, LCT and HCT participants. Significant differences were asterisked.

	All participants (n=103) Mean (SD)	LCT (n=56) Mean (SD	HCT (n=47) Mean (SD	p
Mothers				
Age [years]	31.70 (3.78)	32.41 (3.92)	30.88 (3.47)	**0.041***
Education [high educated %][1]	96.12	98.21	93.62	0.229
Financial satisfaction [7-points scale][2]	5.54 (0.89)	5.53 (0.78)	5.55 (1.02)	0.91
EPDS score [0-30][2]	6.86 (4.51)	6.64 (4.55)	7.13 (4.49)	0.589
Ln cortisol level in defatted milk [ng/ml]	5.54 (0.89)	5.53 (0.78)	5.55 (1.02)	0.238
Infants				
Sex [boys %][1]	57.28	53.57	61.70	0.406
Birth weight [kg]	3.47 (0.48)	3.40 (0.44)	3.56 (0.51)	0.079
Gestational age [weeks]	39.83 (1.42)	39.75 (1.36)	39.94 (1.50)	0.502
Age [months]	12.33 (0.72)	12.35 (0.60)	12.30 (0.84)	0.742
Surgency/extraversion	5.36 (0.43)	5.37 (0.40)	5.35 (0.47)	0.799
Negative affectivity	4.13 (0.43)	4.14 (0.45)	4.13 (0.41)	0.887
Orienting regulation	3.85 (0.68)	3.87 (0.68)	3.82 (0.68)	0.705
Approach	5.67 (0.65)	5.65 (0.65)	5.70 (0.66)	0.705
Vocal reactivity	4.97 (0.76)	5.00 (0.75)	4.95 (0.78)	0.740
High-intensity pleasure	5.89 (0.61)	5.87 (0.63)	5.91 (0.58)	0.774
Smiling & laughter	4.63 (0.82)	4.66 (0.72)	4.60 (0.93)	0.727
Activity level	4.72 (0.74)	4.74 (0.76)	4.70 (0.72)	0.776
Perceptual sensitivity	3.71 (0.92)	3.78 (0.89)	3.63 (0.95)	0.391
Sadness	3.75 (0.85)	3.77 (0.88)	3.73 (0.81)	0.794
Distress to limitation	4.46 (0.67)	4.47 (0.67)	4.44 (0.68)	0.860
Fear	3.00 (0.94)	2.96 (0.92)	3.04 (0.97)	0.675
Falling reactivity	4.76 (0.68)	4.77 (0.72)	4.74 (0.64)	0.825
Low-intensity pleasure	4.43 (0.93)	4.46 (0.91)	4.40 (0.97)	0.740
Cuddliness	5.70 (0.66)	5.68 (0.67)	5.72 (0.64)	0.736
Duration of orienting	3.40 (0.81)	3.37 (0.87)	3.43 (0.74)	0.688
Soothability	5.29 (0.69)	5.36 (0.65)	5.21 (0.72)	0.266

[1]For strength, we calculated percentage and hi^2 test.
[2]For scores we calculated median, range and U-Mann-Whitney test.

The ELSQ score of the mothers ranged between 0 and 11 traumatic events. Only 15.5% of the women in the study samples did not experience any traumatic event, whereas nearly 46% had more than two. Emotional violence reported by 36% of the mothers was the most frequent traumatic event. None of the women in the study group was adopted or suffered from warfare.

We found a significant negative correlation between maternal EPDS score, infant vocal reactivity (r=-0.2), and falling reactivity (r=-0.2). In contrast, we found no correlation between maternal ELSQ score, breast milk cortisol level, and infant temperamental traits (Tab.3).

Table 3. Spearman's rank correlation coefficient between maternal ELSQ score, ln cortisol level in milk, EPDS score, age and infant temperamental traits. Significant correlations were asterisked.

	ELSQ score	Cortisol level	EPDS score	Age
Approach	0.00	0.10	0.01	-0.08
Vocal reactivity	-0.02	0.03	**-0.20***	-0.06
High-intensity pleasure	-0.01	0.14	-0.05	-0.10
Smiling & laughter	0.01	-0.04	-0.08	-0.13
Activity level	0.02	0.07	-0.01	-0.05
Perceptual sensitivity	-0.01	0.07	-0.05	-0.04
Sadness	0.01	0.03	0.09	0.03
Distress to limitation	0.04	0.12	0.16	0.14
Fear	0.02	0.13	0.07	0.09
Falling reactivity	-0.06	-0.08	**-0.20***	-0.18
Low-intensity pleasure	-0.01	0.06	-0.19	-0.17
Cuddliness	0.00	0.19	-0.05	0.00
Duration of orienting	0.03	-0.06	-0.12	-0.19
Soothability	-0.06	0.05	-0.10	0.02

The results of MANCOVA models did not indicate any association between maternal childhood trauma and infant temperament. Infants of LCT and HCT mothers did not differ in temperamental traits loading on the three main factors - surgency/extraversion (Wilks λ=0.97, $F_{(6,94)}$=0.43, p=0.858), negative affectivity (Wilks λ=0.99, $F_{(5,95)}$=0.12, p=0.988), orienting regulation (Wilks λ=0.99, $F_{(3,97)}$=0.30, p=0.824) (Tab.4). Similarly, the results of univariate analysis did not show the effect of maternal trauma on infant temperamental traits (Sup. 1-3).

Table 4. Results of MANCOVA models for three main scales of infant temperament. Significant effects asterisked.

Model	Wilks λ	F	ηp^2	p
Surgency/ extraversion				
Maternal childhood (LCT-HCT)	0.97	0.43	0.03	0.858
EPDS score	0.95	0.90	0.05	0.495
Negative affectivity				
Maternal childhood (LCT-HCT)	0.99	0.12	0.01	0.988
EPDS score	0.93	1.42	0.07	0.226
Orienting regulation				
Maternal childhood (LCT-HCT)	0.99	0.30	0.01	0.824
EPDS score	0.97	1.12	0.03	0.346

Discussion

This study investigated the association between MCT level, milk cortisol, and infant temperament at 12 months. Based on the data collected from 102 mother–infant dyads, we found no association between MCT and infant temperament. Interestingly, neither the level of milk cortisol was associated with MCT nor with any of the infant's temperamental traits. Simultaneously, our previous study based on the same group showed a significant effect of MCT on infant biological development (Apanasewicz et al., 2020, 2022). More specifically, higher maternal trauma was associated with increased body mass and head circumference during the first year of life (Apanasewicz et al., 2022).

The observed disparity suggests differences in the mechanisms that underlie the effect of MCT on a child's biological and temperamental development. Firstly, the lack of significant effect of MCT on infant temperament may suggest that appropriate and tender maternal care during the first postnatal months might be more significant for the development of offspring temperament than MCT (Choi et al., 2017). Sensitive caregiving, especially in response to fearful, anxious, or distressed infant behaviors, buffers the effect of prenatal stress on infant behavioral development, including temperament (Grant et al., 2010). For instance, quality of caregiving inferred from the attachment style moderated the effect of prenatal stress on infant fearfulness during the second year of life (Bergman et al., 2008).

Secondly, temperament might be less vulnerable to MCT effect than physical growth. The developmental origins of health and diseases hypothesis emphasize that metabolism is highly responsive to maternal stress (Hinde et al., 2015). Both prenatal and postnatal maternal stress affect glucose metabolism and balance between leptin and insulin, resulting in alterations in infants' weight and length (Plagemann, 2008). At the same time, although mental health has been linked to fetal programming, the evidence on temperament in this context is scarce (Padmanabhan et al., 2016).

Finally, the observed differences in the effect of MCT on biological vs temperamental development might source from the methodology. While the assessment of biological development was based on objective physical measurements, infant temperament diagnosis was based on parental description of infant behaviors. As such, it is a tool sensitive to any conditions and parental characteristics that affect the perception of infant behaviors. Indeed, several studies indicated differences between infant temperament assessed using IBQ_R and laboratory assessments by the independent observer (Gartstein & Marmion, 2008; Pauli-Pott et al., 2003). Also, maternal depressive symptoms, sensitivity to infant behavior, and experiences with the infant during daily routines affect temperamental assessments (Hane et al., 2006). Although at least some of these variables were controlled during the analysis, we cannot exclude the possibility that maternal assessment of infant temperament was insufficient to find subtle links between MCT and infant temperament.

Maternal prenatal stress is one of the most frequently discussed factors affecting offspring temperament and the occurrence of behavioral problems in the recent literature (Graignic-Philippe et al., 2014; Plant et al., 2018). In light of recent studies, pre-pregnancy stress is especially interesting in this respect because fetal development is not directly affected. Some studies indicate that MCT is transmitted to the offspring and generates modification to infant behavior (Bouvette-Turcot et al., 2020; Choi et al., 2017). Contrary to our null results, Choi et al. (2017) noted higher negative affectivity in infants born to mothers with HCT. Even though the infant age in this study was similar to ours, other sample characteristics differ between ours and their study. Firstly, mothers from their study had lower socioeconomic status. Secondly, compared to our sample, these mothers had a higher prevalence of postpartum depression (15% vs. 29% and 25%) (Choi et al., 2017), which might stem from their low socio-economic status. Finally, long-lasting exclusive breastfeeding in our sample could increase maternal–infant bonding and prevent negative behavioral effects in the offspring. For instance, prolonged lactation buffered against maternal postpartum depression, which was demonstrated to have a detrimental effect on infant attachment and further temperament (Figueiredo et al., 2014). Moreover, breastfeeding mothers showed a more sensitive and “warmer” attitude toward infant needs and behavior (Peñacoba & Catala, 2019). In our study group, 88% of children were still breastfed at 12 months old, whereas no information about infant feeding practices was given in their study (Choi et al., 2017).

Recent studies have also indicated a relationship between MCT and temperament among children older than those in our sample (Bouvette-Turcot et al., 2020; Robinson et al., 2019). During the post-infancy period, children of higher MCT were characterized by higher negative affectivity (Bouvette-Turcot et al., 2020) and anxiety (Robinson et al., 2019). This may suggest that associations between MCT and child temperament will appear during the later periods of life when temperament is fully established. Even though temperament is considered relatively constant throughout individual life, some changes in temperamental traits are noticeable during consecutive life stages (Rothbart, 1989). Infant temperament predicts temperament in later childhood; however, the considerable heterotypic continuity of temperament is visible (Slobodskaya & Kozlova, 2016). Thus, further research, especially in longitudinal setup in subsequent childhood and adolescence periods, could give a more nuanced picture of the effect of MCT on offspring’s temperament. Studies in longitudinal setup could also allow the identification of important early temperamental risk factors that might affect subsequent emotional and mental problems among descendants of mothers who were exposed to trauma (Yehuda et al., 2001; Zutshi et al., 2021).

We found no association between milk cortisol and infant temperament. Although the effect of milk cortisol on infant temperament was investigated in several studies, the results are inconsistent. Similarly to our result, Hechler et al. (2018) found no relationship between infant crying and breast milk cortisol concentration. Interestingly, the changes in the circadian rhythm of milk cortisol release also were not linked with infant behavior (Toorop et al., 2020). Contrastingly, Grey et al. (2013) found that higher milk cortisol increases infant negative affectivity at 3 months but is unrelated to surgency/extraversion and orienting/regulation. In another study, infants exposed to higher cortisol levels in milk were characterized by higher reactivity to laboratory-induced fear, but not by mother-reported fearfulness(Nolvi et al., 2018). On the other hand, female rats exposed to higher milk corticosteroids were less fearful in stressful situations (Catalani et al., 2002). Also, milk cortisol concentration was positively related to impulsive behavior (Dettmer et al., 2018), higher self-confidence (Sullivan et al., 2011) (but see Hinde et al., 2015), and nervousness (Hinde et al., 2015). In the light of inconsistent results of recent studies, it is unclear if the milk cortisol concentration is associated with infant temperament. It cannot be excluded that observed effects depend on the offspring's age and/or lactation stage. Our study focused on milk cortisol; however, milk includes many components that may protect against transmitted negative effects of trauma on infant temperament, such as oxytocin, endogenous cannabinoids, micro-RNA, fatty acids, and microbiome (Allen & Dwivedi, 2020; Caba-Flores et al., 2022; Robertson et al., 2017). Since it should not be excluded that other factors from milk might moderate or mediate a relation between MCT and infant temperament.

Even though the study was carefully designed to quantify the effect of MCT on infant temperament, it did not avoid some limitations. Although maternal mental health status was assessed based on EPDS 5 months after postpartum, no information was collected about pregnancy or pre-pregnancy episodes of mental disorders (Grabow et al., 2017) and treatment history (Reuveni et al., 2021). Hence, we could not verify if and to what extent the mothers were affected by trauma. Furthermore, we did not control mother-infant bonding. However, the lack of association between maternal trauma and child temperament could be due to strong bonding, as indicated by frequent and exclusive breastfeeding and extended time devoted to infant care. Finally, we did not collect information about maternal resilience, which might mediate or moderate the effect of MCT on offspring behavior (Sciaraffa et al., 2018). Therefore, future research should control for all of these significant parameters.

Our study indicated that maternal childhood trauma level is not related to infant temperament at twelve months. Also, maternal childhood trauma was not associated with breast milk cortisol concentration when children were five months old, which may suggest that other milk bioactive factors might be responsible for shaping infant temperament.

Author contributions

A.A. contributed to the conception and design of the study, collected data, conducted the statistical analysis of data, and drafted the manuscript, M.M. drafted manuscript, M.P. and P.W. collected data and commented on the manuscript, N.J. and M.K-K. contributed to the study design, performed cortisol quantification, and commented on the manuscript, A.Z. contributed to design of the study, supervision, managed the data collection, funding beneficiary, and commented on the manuscript.

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Data availability statement

The data set analyzed during the current study is available from the corresponding author on request.

Competing interests

We declare no competing interests.

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Supplementary

Supplementary 1. ANCOVA models for behavioral traits which created surgency/ extraversion.

	$F_{(1,101)}$	p
Approach		
Maternal childhood (LCT-HCT)	0.23	0.631
EPDS score	0.00	0.996
Vocal reactivity		
Maternal childhood (LCT-HCT)	0.02	0.895
EPDS score	4.10	**0.045***
High-intensity pleasure		
Maternal childhood (LCT-HCT)	0.24	0.625
EPDS score	0.50	0.480
Smiling & laughter		
Maternal childhood (LCT-HCT)	0.25	0.619
EPDS score	0.37	0.545
Cuddliness		
Maternal childhood (LCT-HCT)	0.22	0.639
EPDS score	0.02	0.888
Soothability		
Maternal childhood (LCT-HCT)	1.14	0.288
EPDS score	0.91	0.342

Supplementary 2. ANCOVA models for behavioral traits which created negative affectivity.

	$F_{(1,101)}$	p
Activity level		
Maternal childhood (LCT-HCT)	0.11	0.746
EPDS score	0.00	0.968
Sadness		
Maternal childhood (LCT-HCT)	0.18	0.670
EPDS score	0.47	0.496
Distress to limitation		
Maternal childhood (LCT-HCT)	0.01	0.922
EPDS score	2.51	0.117
Fear		
Maternal childhood (LCT-HCT)	0.12	0.703
EPDS score	0.15	0.731
Falling reactivity		
Maternal childhood (LCT-HCT)	0.00	0.988
EPDS score	5.15	**0.025***

Supplementary 3. ANCOVA models for behavioral traits which created orienting regulation.

	$F_{(1,101)}$	p
Perceptual sensitivity		
Maternal childhood (LCT-HCT)	0.50	0.481
EPDS score	0.19	0.664
Low-intensity pleasure		
Maternal childhood (LCT-HCT)	0.02	0.889
EPDS score	3.07	0.083
Duration of orienting		
Maternal childhood (LCT-HCT)	0.22	0.637
EPDS score	1.70	0.196

8. Conclusions

The present study addressed the complex issue of the relationship between maternal traumatic stress in childhood and the biological and psychological development of the offspring in the first year of life. The analysis showed a significant relationship:

1. The number of traumatic events that the mothers experienced during childhood was positively and directly related to infant biological development.
2. The children whose mothers had high levels of childhood trauma characterized higher weight and bigger head circumferences at the ages of 5 and 12 months. However, their body length did not differ.
3. Infant temperament was not related to the mother's level of childhood trauma. It was supposed that exclusive breastfeeding among participating mothers might be a reason for the observed results. Specifically, breastfeeding is positively associated with forming a good emotional bond between mother and child.
4. The cortisol level in breast milk was associated with neither maternal childhood trauma nor infant temperamental traits.