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Impact of healthy pregnancy and lifestyle in mothers on developmental delay in their offspring: a strength-based analysis of a longitudinal study among indigenous children in Australia

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Abstract

Introduction Extensive literature has investigated the prenatal risk factors of developmental delay in children, with evidence highlighting the impact of prenatal health, mental health, and behavioural factors. While a deficit discourse has underscored Indigenous health research and policies, strengths-based approaches provide an opportunity to reframe this discourse, to illustrate and celebrate the strength and resilience of Australian Indigenous families. As such, this study aimed to identify the protective impact of healthy pregnancy and lifestyle in mothers on developmental delay in Indigenous Australian children; and whether it varies by child birthweight adjusted for gestational age. Further, we also tested whether child birthweight for adjusted gestational age mediates the association between a healthy pregnancy and lifestyle in mothers and developmental delay in their Indigenous offspring.

Methods Strength-based analysis was conducted using data from 8 longitudinal waves of LSIC study in Australia. Random-effect models were used to longitudinally measure the impact of maternal healthy pregnancy and lifestyle on developmental delays in their children between 2008 and 2018. A composite score (ranging from 0 to 3, score = 3 refers to most healthy pregnancy) was created for a healthy pregnancy and lifestyle variable using three criteria – (1) a lack of medical conditions, (2) no substance use including smoking/alcohol/illicit drugs, and (3) intake of iron/folic acid during pregnancy. All models were adjusted for potential covariates.

Results Of the 780 mother-child dyads analysed, 65.4% of mothers reported healthy pregnancy and lifestyle; while 73.5% of children born with a recommended appropriate birthweight adjusted for gestational age, and 91.4% reported no developmental delays. In children born in the recommended range of appropriate birthweight adjusted for gestational age, healthy pregnancy in mothers (most healthy, aOR: 4.76, 95% CI: 1.12–20.18; and 2nd most healthy, aOR: 4.02, 95% CI: 1.09–14.83) was protective against development delay compared to maternal unhealthy pregnancy. Living in remote areas (vs. major city, and regional) was also found to be protective against developmental delay in those who were born within the recommended range of birthweight adjusted for gestational age. Further, the current study found that child birthweight for adjusted gestational age does not have any mediating effect on the association between healthy pregnancy in mothers and developmental delay in their children.

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Conclusion This strengths-based study suggests healthy pregnancy in mothers should be advocated to prevent developmental delay in their offspring in the Australian Indigenous population. The findings also found living in remote areas has a protective effect against developmental delay in Indigenous children who born within the recommended range of birthweight adjusted for gestational age. These findings have implications for challenging and reframing the deficit discourse surrounding Indigenous Australian health research and policymaking. Further studies are needed to investigate the positive relationship between Indigenous Australians' health and social and emotional well-being (SEWB) and their connection to their country and culture.

Keywords Healthy pregnancy, Lifestyle, Developmental delay, Maternal and child health, Children and adolescents, Paediatrics, Strength-based analysis, Mediation analysis, Indigenous population, Australia

Introduction

Historical and intergenerational trauma, displacement, racism, and loss of cultural heritage continue to influence the social and emotional wellbeing (SEWB) of Aboriginal and Torres Strait Islander peoples (hereafter, Indigenous Australians) [35, 56, 61, 69]. Before colonisation, Indigenous peoples in Australia evolved sophisticated complex societies, local knowledge systems and cultures that enabled them to adapt and thrive in shifting socio-environmental conditions [9, 54]. Furthermore, despite immense hurdles given by historical, intergenerational, and current trauma, relocation, racism, and loss of cultural legacy, Indigenous peoples continue to display extraordinary resilience, maintaining and cultivating culture and SEWB (i.e. A physically healthy, culturally intact and spiritually connected person [9] in the Indigenous community) [9, 69]. Regardless, Indigenous Australian children experience an increased burden of neurodevelopmental difficulties. In a cohort of children born in Western Australia between 1983 and 2010, the estimated prevalence of intellectual impairment (ID) or autism spectrum disorders (ASDs) was more than twice among Indigenous children compared to non-Indigenous children [8]. Similarly, analysis of birth records from 1996 to 2005 showed that Indigenous children had an increased risk of postneonatal and pre/perinatal cerebral palsy (CP) compared to non-Indigenous children [7]. Evidence suggests that the burden of developmental challenges in Indigenous Australian children is highest in regional/remote areas of Australia, with studies revealing a significant prevalence of and burden from fetal alcohol spectrum disorders (FASDs) among Indigenous Australian children in remote communities [27], with long-term developmental delays [22, 21, 28, 50–53, 74] and increased rates of hospitalisation observed among this cohort [23]. Given these long-term impacts, extensive research has sought to investigate the factors that impact children's risk of developmental delay.

Existing evidence highlights the critical role that prenatal health has on children's neurodevelopment. For instance, research has shown an association between prenatal diabetes and children's cognitive development [2]; gestational hypertensive diseases in mothers associated with increased risk of reduced verbal ability in offspring [79]; and maternal obesity in the prenatal period is linked with poorer child outcomes such as neurodevelopment, problem-solving and fine-motor skills, executive functioning, and working memory [57]. Further, studies have revealed an association between maternal iron deficiency and autism, schizophrenia, and abnormal brain structure [33], as well as low iodine intake during pregnancy and poorer language skills and school performance in children [1]. Mental health and well-being are also critical determinants of children's developmental outcomes, with a recent review suggesting an association between poorer maternal mental health and lower IQ scores, neurodevelopment, developmental delay, and motor and language skills in children [75]. Literature has also identified associations between maternal anxiety or depression and children's socioemotional, mental health, and cognitive functioning [37] and prenatal exposure to stress and increased risk for behavioural and mental health problems in children [77]. Behavioural risk factors during pregnancy are also shown to impact child development, with prenatal alcohol exposure [29, 46, 48], tobacco smoking [16, 58], cannabis use [15, 67], and other drug use [32, 68, 80, 81] associated with a range of neurodevelopmental, physical, and behavioural outcomes among children. Furthermore, previous research suggests that gestational age and child birthweight are linked with neurodevelopmental outcomes in children, although the findings across the studies were found to be inconsistent and inconclusive [40, 45].

Australian Government initiatives have focused on supporting the healthy development of Indigenous children [59], including reducing prenatal exposure to risk factors for adverse neurodevelopmental outcomes [14]. However, critics have raised concerns about the deficit discourse that underpins these policies and the research and media surrounding Indigenous health and efforts to reduce disparities between Indigenous and non-Indigenous peoples' health outcomes. This deficit discourse

has often presented Indigenous peoples with a narrative of disadvantage, negativity, and failure; overlooking the historical, socioeconomic, and political structures that created and reinforced disparities; presenting Indigenous peoples' health as an issue requiring fixing; and failing to acknowledge Indigenous people's strengths and capabilities in research, policies, and programs [10, 26, 30]. Further, the deficit discourse approach has failed to recognise Indigenous Australians' resilience to adversity—including how individual and collective resilience is determined by connection to culture, community, ancestry, and country [76]. Culturally safe health services further support healthy pregnancies and births [13, 44].

A strengths-based approach has been proposed as an antidote to the deficit discourse that underscores Indigenous health research and practice [3, 43, 64]. This approach does not deny disparities or mispresent data; instead, it aims to shift the narrative and focus of Indigenous health to identifying capabilities, assets, and strengths among individuals and groups; and identifying alternative mechanisms to address health issues [31]. Bryant et al. [10] suggests three pillars of strengths-based Indigenous health research: (1) resilience approaches that centre on the skills of individuals; (2) social-ecological approaches that focus on individual, community, and structural capabilities in a person's environment; and (3) sociocultural approaches that emphasise social relations, collective identities, and practices. Further, Thurber et al. [72] argue that instead of identifying and modifying risk factors, strengths-based Indigenous health research should focus on identifying protective factors against adverse health outcomes and factors associated with positive health and wellbeing—with policies and programs leveraging these insights to improve health.

Strengths-based approaches have recently been adopted in Indigenous Australian children's health research. For example, Islam et al. [42] analysed data from the Longitudinal Study of Indigenous Children (LSIC) to identify individual, relational, and geographic factors that were protective against self-harm and suicidality among Indigenous adolescents. Similarly, Westrupp et al. [78] analysed LSIC data to identify perinatal risk and protective factors for children's health. However, no studies have used a strengths-based approach to investigate the factors that are protective against neurodevelopmental outcomes, and none have examined the mediating effect of child birthweight for gestational age on the association between healthy pregnancy and neurodevelopmental outcomes in Indigenous Australian children. Therefore, this study aimed to examine the protective impact of healthy pregnancy and lifestyle in mothers on developmental delay in Indigenous Australian children included in the LSIC; and further tested the mediating effect of child birthweight for gestational age on the association between healthy pregnancy and developmental delay following a strengths-based approach, as previously suggested by Thurber et al. [72].

Methods

Data source and study participants

The LSIC is an ongoing national prospective cohort study that receives financial support and guidance from the Australian Government Department of Social Services. LSIC aims to provide a comprehensive understanding of the experiences encountered by Indigenous children in Australia and to make a meaningful contribution towards formulating and implementing comprehensive strategies to mitigate the existing disparities in life and health outcomes between the Indigenous and non-Indigenous populations of Australia. Additionally, the study emphasises identifying the strengths and resilience exhibited by Indigenous children and adolescents as they navigate through different developmental phases. Previous literature has documented the study design employed for the LSIC [20]. In summary, the LSIC used non-random purposive sampling to select 11 Indigenous communities in Australia to longitudinally track the growth, development, and specific outcomes of more than 1200 Indigenous families, including parents, carers, and adolescents residing in urban, regional, and remote areas. Figure 1 below depicts the geographical distribution of the Indigenous families involved in the LSIC study.

The baseline survey (i.e., first wave) of LSIC began in 2008, involving two distinct cohorts of Indigenous

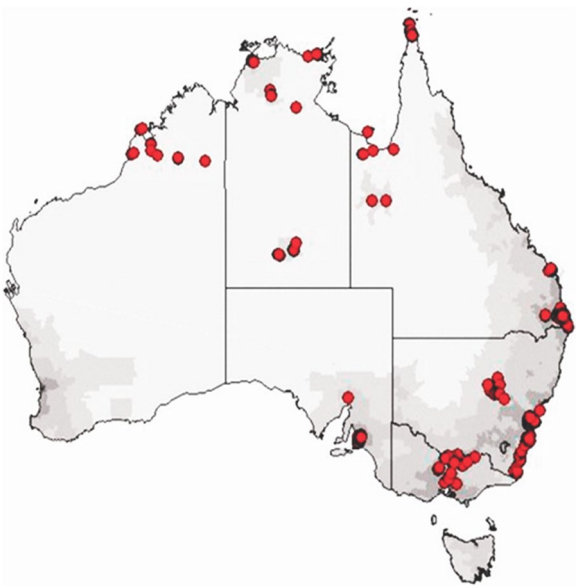

Fig. 1 Geographical distribution of LSIC sample [20]

children. The younger cohort (B-cohort) consisted of children aged 0–1.5 years at the start of the study ($n=812$), and the older cohort (K-cohort) comprised children aged 3.5–5 years at the beginning of the study ($n=586$). These same children continued to participate in subsequent waves of data collection, which took place annually. In-person interviews, administered by an Indigenous Australian, were conducted with the study's participants, including the child, parent, and teacher [20].

The present investigation used data from eight longitudinal LSIC waves (W1, W3, W4, W5, W6, W7, W9 and W11) conducted between 2008 and 2018 involving the same participants linked between waves using unique identifier numbers to incorporate 780 Indigenous adolescents (B-cohort = 484 and K-cohort = 296) from LSIC database. In this study, variables related to the mother of the study child were taken from W1; and the same study child was linked to their data in the following LSIC waves (W3, W4, W5, W6, W7, W9 and W11) for outcome variables of interest (i.e. developmental delay in study child). We incorporated individuals who supplied comprehensive data on the dependent variable (developmental delay), independent variables (healthy pregnancy and lifestyle in mothers) and potential covariates. We performed a complete case analysis (CCA), which means we omitted a case entirely if one or more of the variables of interest were missing as the missing data are likely to be missing at random. Since CCA typically produces unbiased estimates in regression models, we opted to use raw data rather than imputing for missing variables [82]; hence, a total of 618 participants who did not respond to the outcome variable ($n=274$) and explanatory variables ($n=345$) were excluded from the analysis. Total sample characteristics including omitted samples are presented in supplementary material (Appendix 1), and the flow chart for the analytical sample selection process is depicted in Fig. 2.

Measures

The study investigated a variety of variables related to the Indigenous population in Australia, particularly relevant to healthy pregnancy in mothers and developmental delays among Indigenous adolescents aged 11–16 years using the 'Positive Outcome Approach' [71]. Briefly, this approach emphasises the importance of focusing on protective factors (e.g., healthy pregnancy and lifestyle in mothers) and positive outcome variables (e.g., no developmental delays in children) instead of focusing on risk factors and negative outcome variables. Table 1 lists the study's variables.

Cultural integrity

This study enabled Indigenous and non-Indigenous co-authors to learn from one another. It allowed the

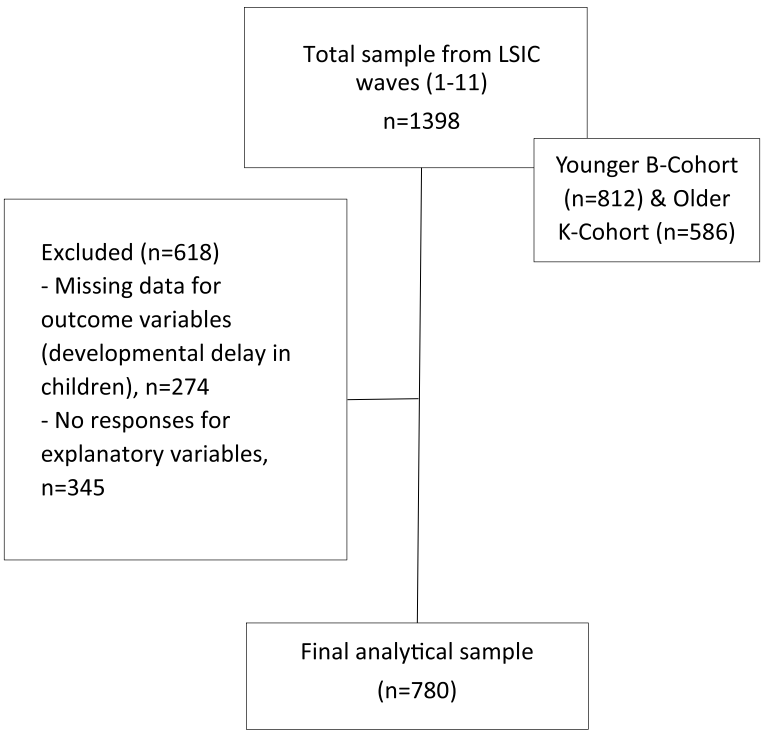

Fig. 2 Flow chart for sample selection

Table 1 List of variables

Variables	Description of variables
Outcome variable	
Developmental delay	Parents of the study child self-reported about their offspring's developmental delay using a validated tool - Parents' Evaluations of Developmental Status (PEDS) [34, 71]. Based on the responses in the PEDS questionnaire, a derived variable was created by the LSIC team whether the study child had any developmental delay (i.e., cognitive, behavioural, speech or physical delays) or not. The Response options were categorised as 'Yes' (coded 0) and 'No' (coded 1). Developmental delay was longitudinally extracted from seven LSIC waves—W3, W4, W5, W6, W7, W9 and W11.
Explanatory variable	
Healthy pregnancy and lifestyle	From the responses of the following items from LSIC W1 - whether mother had any medical condition (i.e. diabetes mellitus, hypertension, pre-eclampsia, anaemia, and depression) during pregnancy (coded 0 for Yes, and 1 for No); whether mother smoked/drank alcohol or used any other substances (Marijuana and/or other illicit drugs) during pregnancy (coded 0 for Yes, and 1 for No); and whether mother took iron and folic acid during pregnancy (coded 0 for No, and 1 for Yes); we created a variable 'healthy pregnancy and lifestyle' with a composite score ranging from 0 to 3 (highest score 3 means most healthy pregnancy while lowest score 0 refers to most unhealthy pregnancy).
Maternal age	The age of the mother during pregnancy was used as a continuous variable and gathered from W1.
Maternal education	The mother's education was categorised into Year 12 and below (coded as 0), Cert I-IV (coded as 1), and Diploma and/or above (coded as 2). The educational status of the mother was obtained from W1.
Maternal employment	Whether the mother is employed or not. Unemployed coded as '0' and Employed code as '1' were obtained from W1.
Area of residence	According to the Australian Statistical Geography Standard (ASGS), and the Australian Bureau of Statistics (ABS), there are five different classifications of remoteness across Australia: Major Cities, Inner Regional, Outer Regional, Remote, and Very Remote [5]. A new variable, Area of Residence, was constructed from the responses. 'Major cities' were coded with '0', while 'inner regional' and 'outer regional' were classified as 'Regional' (coded as 1), and 'remote', and 'very remote' were termed as 'Remote' (coded as 2). This variable was taken from W1.
Child birthweight adjusted for gestational age.	According to the Australian Institute of Health and Welfare (AIHW) report on Australia's mothers and babies [4], "Adjusting birthweight for gestational age allows for differences in a baby's growth status and maturity to be considered when examining their health at birth. Babies are defined as being small for gestational age if their birthweight is below the 10th percentile for their gestational age and sex, and babies are defined as large for gestational age if their birthweight is above the 90th percentile for their gestational age and sex, as determined by national percentiles." Where gestational age was categorised into three - pre-term (< 37 weeks of gestation), term (37–41 weeks), and post-term (≥ 42 weeks), and child birthweight was categorised into three - low birth weight (< 2.5 Kg), healthy birthweight (2.5-<4.5Kg) and high birthweight (≥ 4.5Kg). In LSIC, the variable - 'Child birthweight adjusted for gestational age' was categorised into three - small, appropriate, and large using the following cut-offs - small if the child birthweight is below the 10th percentile for gestational age and sex, while large if the child birthweight is above the 90th percentile for the gestational age and sex. However, in this study, for analytical purposes, we recategorized into two - inappropriate coded as 0 (small/large) and appropriate coded as 1. (Extracted from LSIC W1).

Variables were coded as strengths-based to examine each variable as a protective factor

Noongar/Yamatji Aboriginal co-author (TE) to expand his research capacity and other members of the team to benefit from his leadership, expertise, and knowledge of Indigenous health. Author TE governs, shares, maintains, and enhances his cultural and intellectual legacy by steering the research processes with Indigenous ways of knowing, being, and doing. This study was influenced by a strength-based model and incorporated aspects of the CREATE Aboriginal and Torres Strait Islander quality appraisal tool [36] to ensure cultural integrity. Moreover, the Footprints in Time Steering Committee, which is made up of Indigenous people, governs the overall LSIC study. The Committee advises on the survey questions, the study plan, how to collect data, how to involve the community, issues of ethics and cultural sensitivity, and how to analyse and interpret collected data [20].

Data analysis

First, descriptive statistics (frequency and percentages) were computed for the outcome variable, explanatory variables, and covariates. Later, to conduct a multivariable longitudinal analysis, we considered the hierarchical nature of the study sample, specifically the fact that Indigenous children were nested within households, and households were nested within clusters in the LSIC. Following the LSIC team's recommendations, we utilised a weighted sample and implemented random-effect logistic models with robust standard errors through the bootstrap method [25, 49] to examine the protective influence of healthy pregnancy and lifestyle in mothers against developmental delays in their children, incorporating a random intercept to address geographic clustering of individuals [38]. The analysis was stratified based on the child's birthweight adjusted for gestational age. The variables that yielded a p-value of less than 0.05 in the unadjusted models were included in the adjusted

models. Model fit statistics were also estimated in terms of AIC and BIC. Furthermore, we conducted mediation analysis following Barron and Kenny's approach [6] modified by Iacobucci et al. [41] via Structural Equation Modelling (SEM) using the Stata package 'medsem' [55] to test whether 'child birthweight for gestational age' has any mediating effect in the association between a healthy pregnancy and developmental delay in Indigenous adolescents. The statistical analyses were performed using Stata/SE 14.0, with a 0.05 significance level.

Ethics

The study was approved by the Footprints in Time Steering Committee, and the study's content and fieldwork were approved by the Human Research Ethics Committee of the Australian Institute of Aboriginal and Torres Strait Islander Studies (Ethics code: AIATSIS). The authorship team has been granted access to LSIC data for the study and publication by the Australian Data Archive Dataverse (Application reference no. 440644). All participants provided written informed consent.

Results

Study characteristics

In Table 2, sample characteristics of the study population are portrayed. Overall, the mean age of the study child's mothers was 29.0 years (SD = 6.32). Nearly one-third of the mothers ($n = 584$, 74.9%) completed Year 12 and below during pregnancy, and most were unemployed at the time of gestation ($n = 525$, 67.3%). Approximately two-thirds of mothers ($n = 501$, 64.3%) were living in regional and remote areas during pregnancy. About 73.5% ($n = 573$) of the study children were born with appropriate birthweight for gestational age. Nearly 65.4% ($n = 510$) of the mothers of the study children followed healthy pregnancy and lifestyle during gestation [most healthy ($n = 161$, 20.6%) and 2nd most healthy ($n = 349$, 44.8%), combined].

Table 2 Sample characteristics ($n = 780$)

	Total ($n = 780$)		**No, Developmental delay[d] ($n = 713$, 91.4%)**		**Yes, Developmental delay ($n = 67$, 8.6%)**	
	n	**%**	**n**	**%**	**n**	**%**
Maternal age[a]	Mean = 29.0, SD = 6.32		Mean = 28.9, SD = 6.27		Mean = 30.2, SD = 6.80	
Maternal education						
Year12 and below	584	74.9	542	76.0	42	62.7
Cert I-IV	120	15.4	105	14.7	15	22.4
Diploma and above	76	9.7	66	9.3	10	14.9
Maternal employment						
Unemployed	525	67.3	484	67.9	41	61.2
Employed	255	32.7	229	32.1	26	38.8
Area of residence						
Major cities	279	35.7	246	34.5	33	49.3
Regional	343	44.0	314	44.1	29	43.3
Remote	158	20.3	153	21.4	5	7.4
Child birthweight for gestational age[b]						
Inappropriate	207	26.5	191	26.8	16	23.9
Appropriate	573	73.5	522	73.2	51	76.1
Healthy pregnancy and lifestyle[c]						
0 - Most unhealthy	31	4.0	25	3.5	6	8.9
1 - Not much healthy	239	30.6	216	30.3	23	34.3
2–2nd most healthy	349	44.8	324	45.4	25	37.3
3 - Most healthy	161	20.6	148	20.8	13	19.4

[a] Continuous variable

[b] Child birthweight for gestational age: Inappropriate - Small (< 10th percentile) and/or large (> 90th percentile) for gestational age and sex; Appropriate - Between 10th and 90th percentile for gestational age and sex

[c] Healthy pregnancy and lifestyle: Most unhealthy (History of medical conditions + alcohol/smoking/substance use + did not take iron/folic acid during pregnancy); Not much healthy (any two), Second most healthy (only one); Most healthy (no history of medical conditions + no history of alcohol/smoking/substance use + history of taking iron/folic acid

[d] Developmental delay: Presence of any cognitive, behavioural, speech or physical delays

Table 3 Determinants of developmental delay in indigenous children ($n=780$)

	Developmental delay (No vs. Yes)	
	Unadjusted OR (95% CI)	**Adjusted OR (95% CI)**
Healthy pregnancy and lifestyle		
0 - Most unhealthy	Ref.	Ref.
1 - Not much healthy	2.44 (0.88–6.80)	2.39 (0.87–6.55)
2–2nd most healthy	3.48* (1.24–9.74)	3.30* (1.21–8.99)
3 - Most healthy	3.10* (1.02–9.41)	3.12* (1.06–9.18)
Child birthweight for gestational age		
Inappropriate	Ref.	-
Appropriate	0.85 (0.47–1.54)	
Maternal age[1]	0.96 (0.93–1.01)	-
Maternal education		
Year12 and below	Ref.	-
Cert I-IV	0.54 (0.29–1.01)	
Diploma and above	0.51 (0.24–1.08)	
Maternal employment		
Unemployed	Ref.	-
Employed	0.75 (0.44–1.26)	
Area of residence		
Major cities	Ref.	Ref.
Regional	1.45 (0.85–2.45)	1.56 (0.91–2.67)
Remote	4.11** (1.56–10.74)	4.21** (1.60–11.07)
Model fit statistics		
AIC	-	452.69
BIC	-	480.65

Level of significance: *p<0.05, **p<0.01

[1] Continuous variable

Table 2 also shows that the majority (91.4%, $n=713$) of the total study children did not experience any developmental delay (vs. $n=67$, 8.6% reported developmental delay). Among those children who reported no developmental delays ($n=713$), the mean maternal age was 28.9 (SD = 6.27), 73.2% ($n=522$) born with appropriate child birthweight for gestational age, and 66.2% ($n=472$, most and 2nd most health pregnancy combined) of the study child's mother followed healthy pregnancy and lifestyle. While among the children who had developmental delays ($n=67$), the mean maternal age was 30.2 (SD = 6.80), around three-quarters ($n=51$, 76.1%) born with appropriate child birthweight for gestational age, and 56.7% ($n=38$) of the mothers followed health pregnancy and lifestyle (most and 2nd most health pregnancy combined).

Determinants of developmental delay (strength-based analysis)

Using random-effect models, Table 3 demonstrates that the most healthy (adjusted OR: 3.12, 95% CI: 1.06–9.18, $p=0.038$) and 2nd most healthy (aOR: 3.30, 95% CI: 1.21–8.99, $p=0.019$) pregnancy and lifestyle in mothers were significantly protective against developmental delay in their children compared to mothers who reported unhealthy pregnancy and lifestyle. Living in remote areas (aOR: 4.21, 95% CI: 1.60–11.07, $p=0.003$) was significantly associated with the reduced risk of developing developmental delay in children compared to those living in regional and major cities.

Healthy pregnancy and lifestyle in mothers vs. developmental delays (stratified by child birthweight adjusted for gestational age)

In Table 4, random-effect logistic models were used to investigate the protective effect of healthy pregnancy and lifestyle in mothers on developmental delay in children born with appropriate and inappropriate birthweight for gestational age, respectively. Adjusted longitudinal analysis revealed that among those who were born with appropriate birthweight for gestational age, mothers with the most healthy pregnancy (aOR: 4.66, 95% CI: 1.32–16.46, $p=0.017$) and mothers with the 2nd most healthy pregnancy (aOR: 3.50, 95% CI:

Table 4 Odds of healthy pregnancy and lifestyle in mothers protecting against developmental delays (stratified by child birthweight for gestational age)

	No developmental delay - inappropriate birthweight for gestational age ($n=207$)		No developmental delay - appropriate birthweight for gestational age ($n=573$)	
	Unadjusted OR (95% CI)	**Adjusted OR (95% CI)**	**Unadjusted OR (95% CI)**	**Adjusted OR (95% CI)**
Healthy pregnancy and lifestyle				
0 - Most unhealthy	Ref.	Ref.	Ref.	Ref.
1 - Not much healthy	1.48 (0.15–14.35)	0.94 (0.09–9.44)	2.79 (0.86–9.04)	2.68 (0.85–8.47)
2–2nd most healthy	2.41 (0.23–25.37)	1.48 (0.14–15.71)	3.97* (1.24–12.64)	3.50* (1.13–10.79)
3 - Most healthy	0.93 (0.09–9.56)	0.60 (0.05–6.27)	4.80* (1.30–17.69)	4.66* (1.32–16.46)
Maternal age	0.91* (0.83–0.99)	0.92 (0.84–1.01)	0.98 (0.94–1.03)	-
Maternal education				
Year12 and below	Ref.	Ref.	Ref.	-
Cert I-IV	0.54 (0.13–2.15)	0.64 (0.15–2.69)	0.55 (0.26–1.11)	
Diploma and above	0.14* (0.03–0.56)	0.16* (0.03–0.75)	0.81 (0.32–2.09)	
Maternal employment				
Unemployed	Ref.	-	Ref.	-
Employed	0.59 (0.20–1.72)		0.81 (7.33–18.55)	
Area of residence				
Major cities	Ref.	-	Ref.	Ref.
Regional	2.42 (0.68–8.52)		1.29 (0.72–2.33)	1.41 (0.77–2.57)
Remote	1.43 (0.38–5.32)		14.64** (1.95–109.60)	15.27** (2.03–114.73)
Model fit statistics				
AIC	-	116.88	-	336.49
BIC	-	143.54	-	366.95

Level of significance: *$p<0.05$, **$p<0.01$

1.13–10.79, $p=0.029$) were significantly protective against developmental delay in their children compared to mothers who reported unhealthy pregnancy and lifestyle, respectively. Moreover, living in remote areas (aOR: 15.27, 95% CI: 2.03–114.73, $p=0.008$) has a protective effect against developmental delay in children born with appropriate birthweight for gestational age compared to living in regional areas and major cities. Furthermore, offspring of mothers with higher education (i.e. Diploma and above) have about 86% (aOR: 0.14, 95% CI: 0.03–0.56, $p=0.024$) to 84% (aOR: 0.16, 95% CI: 0.03–0.75, $p=0.037$) lower odds of developmental delay compared to offspring of mothers without higher education among the children who born with inappropriate birthweight adjusted for gestational age. Since the effect size did not change significantly, maternal education can be considered as a non-effect modifier.

Mediation analysis

The mediation analysis following modified Barron and Kenny's approach via SEM found that child birthweight adjusted for gestational age does not have any mediation effect in the relationship between healthy pregnancy in mothers and developmental delay in children (Mediation model in Supplementary File 2).

Discussion

This strength-based study examined the protective impact of healthy pregnancy and lifestyle in mothers on Australian Indigenous children's risk of developmental delay using the LSIC data. The analysis suggests that healthy pregnancy and lifestyle (most healthy and 2nd most healthy) were protective against developmental delay in children with an appropriate birthweight for gestational age. To our knowledge, this is the first study to identify the composite of protective factors in Indigenous Australian children born with the recommended appropriate gestational age for birth. These findings are consistent with previous literature in non-Indigenous populations and highlight the importance of promoting optimal health leading up to and during pregnancy - particularly those that reduce the risk of noncommunicable diseases such as diabetes [2], hypertensive diseases [57, 79]. These findings also align with current literature that demonstrates the importance of intake of sufficient iron [33] and iodine [1] alongside avoiding alcohol exposure

[29, 46, 48], tobacco smoke [16, 58] and recreational drugs [15, 32, 67, 68, 80, 81] have protective impact against the risk of developmental delays in children. Consistent with previous study [19], the analysis also revealed that healthy maternal pregnancy and lifestyle behaviours were not statistically significantly protective against developmental delay in children born with an inappropriate birthweight for gestational age - a known risk factor for developmental delay in children up to three years [39]. This could be attributable to methodological restrictions caused by various factors, including geographic locations, history of colonisation, ethnic backgrounds, social relationships, and economic elements [45].

While the Australian Government has prioritised policies and programs to support the healthy development of Indigenous children [32], these initiatives are often framed within a deficit discourse - aiming to reduce risk factors of developmental delay in Indigenous Australians [13]. However, our findings illustrate an opportunity to challenge and reframe this deficient discourse to a strengths-based approach that highlights and promotes the protective factors surrounding healthy pregnancy and lifestyle for the healthy development of Indigenous Australian children [3, 43, 64]. This approach could also focus on identifying healthy pregnancy and lifestyle factors that reside beyond individuals, such as the capabilities and assets of groups and communities [31]. For instance, further research could explore the socioeconomic determinants of healthy pregnancy and lifestyle factors in Indigenous Australian mothers.

Our research also revealed that higher maternal education is associated with a lower risk of developmental delay among children born at an inappropriate birthweight for gestational age. This finding was consistent with previous literature showing a positive association between maternal education and higher cognitive, motor, and language scores among children born preterm [62]. This finding is novel as past research mostly focused on the impact of maternal education on non-Indigenous children's development. Our findings suggest that promoting maternal education could have a dual role in protecting against developmental delay in children and as an overall goal in promoting Indigenous Australians' health and wellbeing. However, such an approach must view Indigenous Australians' mental health from a SEWB framework, which—contrary to Western concepts of health and medicine—acknowledges the connection between one's health and well-being and that of one's family, community, country, and ancestors [12]. This holistic, connected, and relational view is often absent from policies and measures of Indigenous health and well-being [11], yet it is central to identifying and promoting the SEWB of Indigenous Australians [66].

The research identified that maternal residence in a remote area, compared to a major city and regional areas, was protective against developmental delay in Indigenous Australian children with an appropriate birthweight for gestational age. This finding was surprising as previous literature has revealed mixed results regarding the different health outcomes of Indigenous children in regional, remote areas of Australia and cities. For instance, one study identified an increased risk of developmental delay among Indigenous Australian children in regional areas compared to those cities [70], and another showed that having a mother who lived in a less remote region was associated with reduced risk of adverse health outcomes in Indigenous Australian children [78]. However, other research showed no significant difference between premature young children in rural areas and those in urban areas regarding increased risk of functional disability [65]. Further, analysis of national health and social surveys from 2002 to 2012/2013 showed that Indigenous Australian adults living in remote areas, compared to those living in non-remote areas, were significantly more likely to report good-excellent for self-assessed health status, less likely to have high-very high psychological distress, and less likely to report being extremely sad some of the time, and less likely to have asthma [18]. One hypothesis to explain the improved health outcomes of Indigenous Australians in regional areas compared to cities could be the protective effect of one's connection to family, traditional lands, culture, and language in regional parts of Australia [63, 76]. For instance, Salmon et al. [66] argue that connection to the country is important for Indigenous Australians' health and SEWB because it provides a sense of belonging, nurturing, and empowerment—with connection or disconnection to lands historically resulting in health and ill health determinants. Similarly, Trzepacz et al. [73] report how Indigenous Australians recalled the disconnection to country and culture they experienced living in urbanised settings and how it negatively impacted their mental health and well-being. As such, public health research and practice could do more to acknowledge and investigate the impact of connection to country and culture on the health and SEWB of Indigenous Australians.

Limitations

These findings should be considered alongside the study's limitations. First, even though the study's sample size was reasonable ($n=780$), some participants of the overall cohort could not be included due to missing responses, which may increase the risk of selection bias. Moreover, the included sample is only representative of Indigenous populations and lacks generalisability to the overall Australian population (e.g., non-Indigenous population and

other age groups like adults or young adults). Further, the included individuals were not from the Indigenous Protected Areas (IPAs), where the situation could be different compared to other areas of Australia. Second, the study's independent variable (healthy pregnancy and lifestyle) was a composite score based on self-reported health and risk behaviours (smoking, alcohol consumption, substance use during pregnancy and intake of iron/folic during pregnancy). As such, these findings should be interpreted with caution since previous research has shown that self-reported health information can often provide under/overestimation of the true prevalence [60] and may carry the risk of response bias and/or social desirability bias. Third, our study did not include some key variables such as the nutrition and diet of mothers during pregnancy [17], maternal infection during pregnancy [24, 47], as a component of the independent variable, which has previously been shown to impact on development delays in children – may over/underestimate the current study findings. Moreover, since the LSIC did not have information regarding the use of any pharmaceutical drugs (including fertility drugs) by the mothers we could not ascertain the impact of fertility drugs on developmental delay in children. Additionally, in this study, prenatal care was not included as a protective factor as most of the mothers (98.3%) received regular prenatal checkups during gestation, which would inflate the study findings. Finally, it is worthwhile to mention that the outcome variable (developmental delay) was self-reported by the parents of the study child using a validated tool - Parents' Evaluations of Developmental Status (PEDS), which may be associated with social desirability bias.

Conclusions

The strengths-based study provides novel evidence on the protective effect of healthy pregnancy and lifestyle in mothers on Indigenous Australian children's risk of developmental delay, including for those children born with the recommended appropriate birthweight for gestational age. These findings have implications for challenging the current deficit discourse surrounding Indigenous health and provide a model for reframing public health research and policies from a strengths-based approach. Further, the study revealed the protective effect of living in a regional area on Indigenous children's developmental outcomes. These findings offer insights into better understanding the relationship between Indigenous Australians' connection to country and culture and health outcomes, which is currently lacking in the research literature and policies.

Abbreviations

LSIC	Longitudinal Study of Indigenous Children
SEWB	Social and Emotional Well-being
ID	Intellectual disability
ASDs	Autism spectrum disorders
CP	Cerebral palsy
FASDs	Foetal alcohol spectrum disorders
ASGS	Australian Statistical Geography Standard
ABS	Australian Bureau of Statistics
AIHW	Australian Institute of Health and Welfare
NCLD	National Centre for Longitudinal Data
ADA	Australian Data Archive
NHMRC	National Health and Medical Research Council

Supplementary Information

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Supplementary Material 1.

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Authors' contributions

The study was conceived by Md Irteja Islam (MII) and Alexandra Martiniuk (AM). The first draft was written by MII and Thomas Stubbs (TS). The integrity of the data and the correctness of the data analysis were the responsibility of MII, which had complete access to all the study's data. The cultural input and supervision of the cultural sensitivity of all aspects were offered by Tuguy Esgin (TE), an Indigenous author. AM supervised, reviewed, and thoroughly edited the final draft. All authors have read and agreed to the published version of the manuscript.

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Data availability

Restrictions apply to the availability of the LSIC data. The authorship team obtained written approval (Application reference no. 440644) from NCLD and ADA Dataverse to get access to the de-identified LSIC dataset for analysis and publication. The LSIC dataset is available at https://dataverse.ada.edu.au/dataverse/lsic.

Declarations

Ethics approval and consent to participate

The study was approved by the Footprints in Time Steering Committee, and the study's content and fieldwork were approved by the Human Research Ethics Committee of the Australian Institute of Aboriginal and Torres Strait Islander Studies (Ethics code: AIATSIS). The authorship team has been granted access to LSIC data for the study and publication by the Australian Data Archive Dataverse (Application reference no. 440644). All the participants who took part in the study provided written informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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