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Maternal health and child health disparities among Indigenous and non-Indigenous Australian children: Insights from repeated measures across infancy and adolescence

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ABSTRACT

Background: This study investigates the prevalence and predictors of inferior or less-optimal health (LOPTH) and the Physical Health Outcome Index (PHOIND) among Indigenous and non-Indigenous Australian children from infancy to adolescence, focusing on the impact of maternal health factors.
Methods: Data from the Longitudinal Study of Australian Children (LSAC) (Wave 1, 2004; Wave 8, 2018) were analyzed using binary logistic and linear regression models. Bootstrap resampling was employed to address the small Indigenous sample size, and multicollinearity was assessed using variance inflation factors (VIF), generalized VIF, tolerance, and eigenvalues.
Results: Indigenous infants had a higher prevalence of LOPTH (21.5 %) compared to non-Indigenous infants (12.7 %), with disparities widening in adolescence (Indigenous: 27.0 %; non-Indigenous: 14.9 %). Maternal smoking during pregnancy significantly increased the odds of LOPTH among Indigenous infants (OR = 3.91, 95 % CI: 1.33, 11.49). Maternal physical activity was associated with reduced odds of LOPTH and higher PHOIND scores, indicating protective effects. Maternal psychological distress and stressful life events (SLEs) were linked to lower PHOIND scores in Indigenous infants but not in non-Indigenous infants. Maternal LOPTH significantly impacted non-Indigenous infants' and adolescents' health but was not significant for Indigenous groups, despite Indigenous infants had nearly twice the LOPTH rate, a trend that continued into adolescence.
Conclusion: Persistent disparities between Indigenous and non-Indigenous children are evident, highlighting the impact of maternal health. Culturally tailored interventions addressing maternal mental health, smoking, and physical activity are crucial to reduce inequities and improve health outcomes for Indigenous families in Australia.

1. Introduction

Maternal healthcare is not only crucial for the growth and development of the unborn child but also essential for safeguarding the health and well-being of the mother (Katy, 2020). Improving maternal and child health is a global health priority due to its profound impact on population health outcomes (Ehiri, 2010; Souza et al., 2024; Young et al., 2023). Several studies reported that maternal chronic illness, poor health during pregnancy, and the first year postpartum are growing public health concerns that negatively impact both mother and child (Ingstrup et al., 2012; O'Reilly and Reynolds, 2013; Rumbold et al., 2011). Maternal morbidity remains a significant concern during delivery hospitalization, with evidence of challenges in Australia and other developed countries (Callaway et al., 2006; Jennifer et al., 2011).

Various studies have explored the relationship between maternal health conditions and child health outcomes. Both child development

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and health are influenced by several maternal-perinatal factors, including mental health issues (Ban et al., 2012; Brown et al., 2019; Donald et al., 2019; Lahti-Pulkkinen et al., 2020). Maternal mental health during the prenatal period is particularly important due to its potential physiological effects on the developing foetus (Brown et al., 2019). Maternal poor physical and mental health during the prenatal and postnatal phases heightens the risk of chronic illnesses among children at later life stages (Cena et al., 2021; Lähdepuro et al., 2023; Tegethoff et al., 2011; West et al., 2015). A study reported that maternal depression during pregnancy was associated with higher levels of emotional and behavioral issues in children, even after adjusting for subsequent maternal mental health conditions (Leis et al., 2014). Additionally, unhealthy maternal behaviors during and after pregnancy, such as poor diet, physical inactivity, smoking, and excessive alcohol consumption, have been shown to increase the likelihood of chronic illnesses among children (Alati et al., 2007; Burns et al., 2013; Chavatte-Palmer et al., 2016; Obel et al., 2009; Sutin et al., 2018). Infant health outcomes can profoundly impact long-term physical, cognitive, and emotional development (Buitendijk et al., 2003; Weatherston and Browne, 2016).

Despite global progress in maternal and child health, Indigenous populations worldwide continue to experience significantly poorer outcomes than non-Indigenous populations (United Nations, 2016). This pattern is evident across diverse national contexts. For instance, in Canada, First Nations infants experience mortality rates 2–4 times higher than non-Indigenous infants (Smylie et al., 2010). Similarly, in the United States, American Indian/Alaska Native mothers experience pregnancy-related mortality ratios 2–3 times higher than white mothers (Petersen et al., 2019); and in New Zealand, Māori children have higher rates of preventable hospitalizations compared to non-Māori (Craig et al., 2012). These persistent disparities across developed nations with colonial histories strongly suggest the influence of common structural determinants including systemic discrimination, cultural marginalization, and unequal access to healthcare resources.

In Australia, Aboriginal and Torres Strait Islander peoples constitute 3.2 % of the total population (Australian Bureau of Statistics, 2021). Historical colonization and systemic inequities have contributed to persistent social, economic, and health disparities (Gracey and King, 2009). Compared to non-Indigenous households, Indigenous households experience significantly higher poverty rates (31 % vs. 13 %) and lower educational attainment (26 % vs. 54 % completing Year 12) (AIHW, 2023; Markham and Biddle, 2016). Employment rates are also lower (49 % vs. 76 %), and a disproportionately high percentage of 43 % of Indigenous Australians live in remote areas with limited access to essential services, compared to only 2 % of non-Indigenous Australians (AIHW, 2023; Australian Bureau of Statistics, 2021).

Concerning health outcomes, Indigenous Australians face an 8–10-year gap in life expectancy, diabetes rates three times higher, and double the rate of psychological distress compared to their non-Indigenous counterparts (Abs, 2006; Australian Institute of Health and Welfare, 2024). Indigenous mothers and infants experience poorer perinatal outcomes; for instance, the 2018 Australian Health Report showed that early childhood mortality among Indigenous children was more than twice that of their non-Indigenous children (Date and Government, 2025). Perinatal mental health issues are also more prevalent among Indigenous and minority populations, further exacerbating health inequities (Howard and Khalifeh, 2020; Meltzer-Brody and Stuebe, 2014; Stein et al., 2014). Although life expectancy has improved, the gap between Indigenous and non-Indigenous Australians remains substantial, averaging 15.4 years (Zhao et al., 2022). These entrenched disparities are not only the result of individual circumstances but are also shaped by broader systemic factors. Systemic barriers, including limited access to culturally competent healthcare and the ongoing effects of intergenerational trauma, continue to reinforce these disparities (Durey and Thompson, 2012).

This context underscores the importance of addressing maternal and child health disparities in this study. While previous studies have documented differences in child health outcomes between Indigenous and non-Indigenous Australians, significant gaps remain in understanding the specific role of maternal health and behaviors, particularly across key developmental stages from infancy to adolescence. Many studies either did not stratify their findings by Indigenous status (Ou et al., 2012) or did not adequately address the methodological challenges posed by small Indigenous sample sizes, which limits the reliability of comparative estimates (Ahmad et al., 2021).

This study addressed these gaps by examining the association between maternal physical and mental health, as well as health-related behaviors such as physical activity, diet, alcohol use, and smoking, with health outcomes among Indigenous and non-Indigenous children and adolescents in Australia. Using data from the Longitudinal Study of Australian Children (LSAC), we focused on two critical developmental stages: infancy (aged 0–1 year, Wave 1, 2004) and adolescence (aged 14–15 years, Wave 8, 2018), based on previous literature identifying these as pivotal periods in a child's growth trajectory (Halfon et al., 2017; Susan et al., 2018). According to Halfon et al. (2001), infancy represents a foundational stage in the life course, during which biological, cognitive, and environmental exposures shape early health trajectories (Halfon et al., 2017). Adolescence, in contrast, is a transitional phase characterized by rapid physical, psychological, and behavioral changes that significantly influence long-term wellbeing (Susan et al., 2018). By examining these two pivotal time points within the same cohort and individuals, this study leverages the longitudinal design of LSAC to explore how early maternal health and behaviors relate to child health outcomes over time particularly in the context of persistent disparities between Indigenous and non-Indigenous populations. Moreover, the bootstrap estimation technique was adapted to assess and compare the robustness of health outcomes between Indigenous and non-Indigenous participants, effectively addressing the challenges posed by the smaller sample size of Indigenous participants.

2. Methods

2.1. Study design

Data from the Longitudinal Study of Australian Children (LSAC), a nationwide household survey, were used to gather comprehensive information on the health, socioeconomic status, and demographic characteristics of children, adolescents, and their families. The survey followed a two-stage, stratified, and clustered sampling design using the Health Insurance Commission's (HIC) Medicare database. Further details on the sampling and methodology are available elsewhere (Soloff and Lawrence, 2005). This observational study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines to ensure transparent and comprehensive reporting.

The study focused on two critical developmental stages: infancy (aged 0–1 year) and adolescence (aged 14–15 years). Information regarding maternal physical and mental health, as well as health-related behaviors during pregnancy and the year following childbirth, was collected alongside child health outcomes. For Wave 1, the birth cohort consisted of 5107 infants. Of these, 74 primary caregivers were not biological mothers and hence excluded from the study, resulting in 5033 respondents (230 Indigenous and 4803 non-Indigenous). After removing missing values, the final dataset included 210 Indigenous and 4537 non-Indigenous participants, representing 91.3 % and 94.5 % of the total observations, respectively.

Wave 8 captured the adolescent group (aged 14–15 years) and the total sample size was 3127. The attrition rate from Wave 1 to Wave 8 was 38.77 % ($n = 1980$). Non-mother primary caregivers ($n = 107$) were excluded, leaving 3020 participants (78 Indigenous and 2942 non-Indigenous). After accounting for missing data, the final sample consisted of 74 Indigenous and 2727 non-Indigenous participants,

representing 94.9 % and 92.7 % of their respective groups. The data framework of the total sample is illustrated in Fig. 1.

2.2. Variables

2.2.1. Response variables

Two health outcome variables were considered in this study: General Health Status (GHS) and the Physical Health Outcome Index (PHOIND) score. GHS was available for infants and adolescents, while PHOIND was only available for infants and not for adolescents aged 14–15 years. Each child's biological mother reported the GHS following a predefined five-point Likert scale (1: excellent; 2: very good; 3: good; 4: fair; 5: poor). The ordinal Likert scale values were transformed into dichotomous groups with the binary response variable GHS categorized as: 0 for Optimal Health (OPTH), representing children with relatively excellent health (excellent/very good), and 1 for Less-optimal Health (LOPTH), indicating children with inferior health (good/fair/poor), aligning with previous studies (Rasheda et al., 2009, 2014). The PHOIND score was computed for infants only and served as a composite measure of physical health outcomes. It combined the overall health rating with responses to six screening questions regarding special healthcare needs (Soloff and Lawrence, 2005). These questions assessed whether the child currently requires or uses prescribed medicine excluding vitamins, whether this need is due to health, behavior, or other conditions lasting or expected to last for at least 12 months, and whether the child requires more medical care than is typical for their age due to specific conditions (beyond common colds). The PHOIND score reflected the infants' physical health status at a specific point in time. Higher scores indicate better health, fewer healthcare needs, and a lower likelihood of long-term medical conditions or disabilities requiring intervention. Since the PHOIND was unavailable for adolescents, the analysis of health outcomes for this age group focused solely on GHS.

2.2.2. Explanatory variables

Explanatory variables were selected based on prior literature of maternal health conditions, health-related behaviors, and the variables available in the LSAC dataset (Ou et al., 2010; Qu et al., 2006; Rasheda et al., 2009). Indicators for measuring maternal health status included GHS, use of prescribed medicine during pregnancy for medical conditions, and mental health status. In the LSAC, mothers self-reported their GHS using a 5-point Likert scale when their children were primarily (99.3 %) between 3 and 15 months old. These GHS scores were categorized in the same manner as the infants'/adolescents' GHS, into OPTH and LOPTH.

The use of prescribed medication by mothers during pregnancy for medical conditions such as asthma, gestational diabetes, nausea, hypertensive disorders, and other medical issues requiring antidepressants, anti-allergy, or antibiotic medications was considered as an explanatory variable. This variable was coded as 1 if mothers used any prescribed medicines during pregnancy and 0 otherwise. However, this variable was not directly available on Wave 8. Two maternal mental health-related variables were included: number of stressful life events (SLE) experienced by the mother in the year before the interview (coded as 0 for no events and 1 for one or more events) and psychological distress experienced by the mother in the last month. Maternal psychological distress was assessed using the summed score from the K6 depression scale (DSS). According to the Australian Bureau of Statistics (ABS), K6 DSS scores range from 6 to 30 are categorized as: 6–13 indicating no psychological distress (coded as 0), 14–19 indicating low to moderate distress (coded as 1), and 20–30 indicating severe distress (coded as 2) (Australian Bureau of Statistics, 2012).

Maternal health-related behaviors included daily consumption of vegetables and fruits, as well as the number of days spent engaging in moderate-to-vigorous exercise for at least 30 min in a week. Risk factors related to maternal health included the frequency of smoking per day during the first trimester of pregnancy and the frequency of alcohol consumption per week during the same period. In addition, this study considered other explanatory factors due to their considerable impact on maternal and child health, specifically birth weight status (coded as 0 for $\leq$2500 gm, 1 for >2500 gm) and gestational age (coded as 0 for $\leq$37 weeks, 1 for >37 weeks) (Australian Bureau of Statistics, 2012; Qu et al., 2006). Based on existing literature, the study also incorporated several control variables including type of birth delivery, immunization status, and socio-demographic characteristics such as children's sex, mother's age, language spoken at home, mother's educational attainment, and regional status (Ou et al., 2010; Qu et al., 2006). For adolescents, in addition to the maternal variables, health-related behaviors such as physical activity, smoking, alcohol consumption, and frequency of fruit or vegetable intake were expected to influence outcomes.

2.2.3. Statistical analysis

The analysis followed a survey on statistical principles, considering the study's design features. Data were weighed to adjust for the multi-stage sampling design and non-response, accommodating unequal probabilities of selection. Logistic and linear regression models were fitted to investigate the relationship between predictor variables related

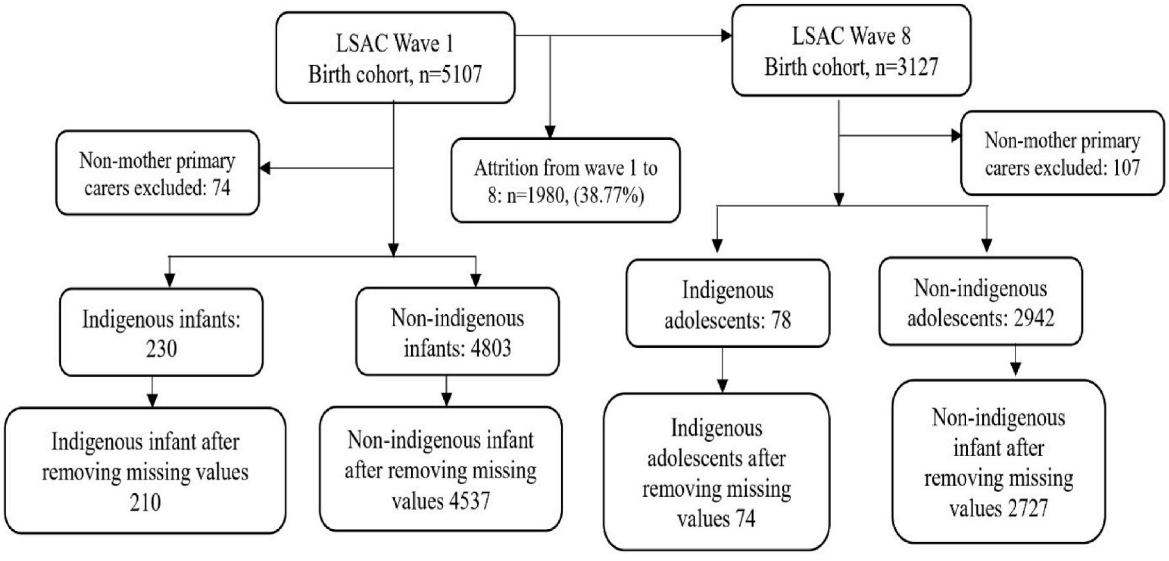


Fig. 1. Data framework.

to maternal health and two infant health outcomes, conducting separate analyses for Indigenous and non-Indigenous infants. Specifically, binary logistic regression assessed children's GHS, while a linear regression model examined the PHOIND score for Indigenous and non-Indigenous participants. Due to the relatively small Indigenous sample size (n = 210 for infants, n = 74 for adolescents), bootstrap resampling was employed (Zoubir and Iskandler, 2007) to enhance the robustness of estimates. We generated 1000 bootstrap samples with replacement from the Indigenous group to create empirical distributions of the estimates for GHS and PHOIND outcomes. This approach allowed more reliable inference by reducing the effects of sampling variability and ensuring that comparisons between Indigenous and non-Indigenous participants were valid. To further leverage the LSAC's longitudinal design, analyses were conducted separately for Wave 1 (2004) and Wave 8 (2018) due to distinct developmental contexts (Halfon et al., 2017; Susan et al., 2018) and a 38.77 % practical constraints, including variable availability described in Section 2.2.1 and 2.2.2 and the attrition rate, particularly impacting Indigenous participants (Gustavson et al., 2012). To further enhance the longitudinal perspective of the study, we examined associations between Wave 1 predictors and Wave 8 adolescent General Health Status (GHS) for participants with complete data (Indigenous n = 74; non-Indigenous n = 2727). Statistical tests were also conducted to assess collinearity, including the computation of variance inflation factors (VIF), with a focus on generalized VIF (GVIF) for categorical variables featuring multiple levels. Across all models, no individual predictor exceeded the VIF threshold of 10, indicating the absence of significant multicollinearity (O'Brien, 2007). Additionally, tolerance and eigenvalues were computed for each independent variable in the regression models, further confirming the absence of multicollinearity (O'Brien, 2007).

3. Results

The sample characteristics of both Indigenous and non-Indigenous participants are summarised in Table 1. Indigenous infants were more likely to be classified as having the LOPTH (21.5 %) compared to non-Indigenous infants (12.7 %). This disparity persisted into adolescence, though the difference became less pronounced. Among Indigenous adolescents, 27.0 % were classified as having the LOPTH, while 14.9 % of non-Indigenous adolescents fell into this category. While the gap in health outcomes between Indigenous and non-Indigenous children remained, it widened from infancy to adolescence, with Indigenous adolescents showing a higher percentage of the LOPTH than their infant counterparts.

For both infants and adolescents, Indigenous mothers were more likely to report the LOPTH. In the infant group, 37.6 % of Indigenous mothers reported the LOPTH, which was higher than the 32.5 % among non-Indigenous mothers. As children transitioned into adolescence, this disparity became more pronounced. Among mothers of Indigenous adolescents, 60.8 % reported the LOPTH, compared to 39.9 % of non-Indigenous mothers. This increase in maternal health issues from infancy to adolescence is notable for Indigenous mothers.

In terms of psychological distress, a larger proportion of Indigenous mothers reported severe psychological distress. Among the infant group, 4.4 % of Indigenous mothers experienced severe distress, compared to 1.4 % of non-Indigenous mothers. This gap widened for adolescents, where 6.8 % of Indigenous mothers reported severe distress, compared to 2.0 % of non-Indigenous mothers. SLEs were reported more frequently by Indigenous mothers in both groups: 54.3 % of mothers of Indigenous infants, increasing to 83.8 % for mothers of Indigenous adolescents, compared to 54.6 % and 78.3 %, respectively, for non-Indigenous mothers.

Among mothers of Indigenous infants, 38.3 % smoked during pregnancy, with 7.9 % being light smokers and 30.4 % being heavy smokers. In contrast, only 15 % of non-Indigenous mothers smoked during pregnancy, including 5 % who were light smokers and 10 % who were

Table 1
Characteristics of the Indigenous and non-Indigenous children and their mothers.

	Wave 1, aged 0–1year (infants)				Wave 8, aged 14–15 years (adolescents)			
	Indigenous *n* = 210		Non-indigenous *n* = 4537		Indigenous *n* = 74		Non-indigenous *n* = 2727	
	n	%	*n*	%	*n*	%	*n*	%
Response variable								
General health status of children								
Optimal health (OPTH)	166	78.5	3980	87.3	54	73.0	2322	85.1
Less-optimal health (LOPTH)	44	21.5	557	12.7	20	27.0	405	14.9
Physical Health Outcome Index (PHOIND) [mean (standard deviation)]	98.0(11.6)		100 (10)		–	–	–	–
Explanatory variables								
General health status of the mother								
Optimal health (OPTH)	131	62.4	3091	67.5	29	39.2	1613	60.1
Less-optimal health (LOPTH)	79	37.6	1446	32.5	45	60.8	1114	39.9
Mothers having any prescribed medicines in pregnancy								
No	119	55.9	3187	70.1	–	–	–	–
Yes	91	44.1	1350	29.9	–	–	–	–
Mother's Mental health-related variables								
Mothers' stressful life events in the year before the interview								
No event	96	45.7	2062	45.4	12	16.2	594	21.7
Yes (1 or more event)	114	54.3	2475	54.6	62	83.8	2133	78.3
Psychological distress (K-6 depression scale summed score)								
No psychological distress	182	85.1	4091	89.9	59	79.7	2412	88.6
Low to moderate psychological distress	21	10.4	382	8.7	10	13.5	259	9.3
Severe psychological distress	7	4.4	64	1.4	5	6.8	56	2.0
Mother's health behavior related variables								
Smoking frequency								
None	133	61.7	3906	85.0	47	63.5	2466	90.7
Less than 10/day (Light smoker)	16	7.9	206	5.0	12	16.2	157	5.5
More than or equal 10/day (Heavy smoker)	61	30.4	425	10.0	15	20.3	104	3.8
Number of days per week alcohol was consumed								
Never/rarely	176	83.1	3043	68.7	54	73.0	1408	51.3
once or more in a week	34	16.9	1494	31.3	20	27.0	1319	48.7
Number of days in a week mothers engage in at least 30 min of exercise								
None (0 days)	85	40.8	1253	29.1	32	43.2	955	35.1
1–3 days/week	83	38.9	2249	48.5	32	43.2	1244	45.5
More than 3 days/week	42	20.3	1035	22.4	10	13.5	528	19.4
Usual daily serves of vegetable intake by mothers								
Never/rarely	87	42.6	873	20.7	–	–	–	–
One or more times/day	123	57.4	3664	79.3	–	–	–	–
Usual daily serves of fruit intake by mother								
Never/rarely	112	53.8	1424	32.8	–	–	–	–
One or more times a day	98	46.2	3113	67.2	–	–	–	–
Perinatal health variables								
Birth weight of study child					–	–	–	–

(*continued on next page*)

Table 1 (*continued*)

	Wave 1, aged 0–1year (infants)				Wave 8, aged 14–15 years (adolescents)			
	Indigenous $n = 210$		Non-indigenous $n = 4537$		Indigenous $n = 74$		Non-indigenous $n = 2727$	
	n	%	*n*	%	*n*	%	*n*	%
Less than 2500gm	31	15.3	241	5.7				
>2500gm	179	84.7	4296	94.3	–	–	–	–
Gestational age					–	–	–	–
≤37 weeks	42	19.8	563	12.7	–	–	–	–
>37 weeks	168	80.2	3974	87.3				

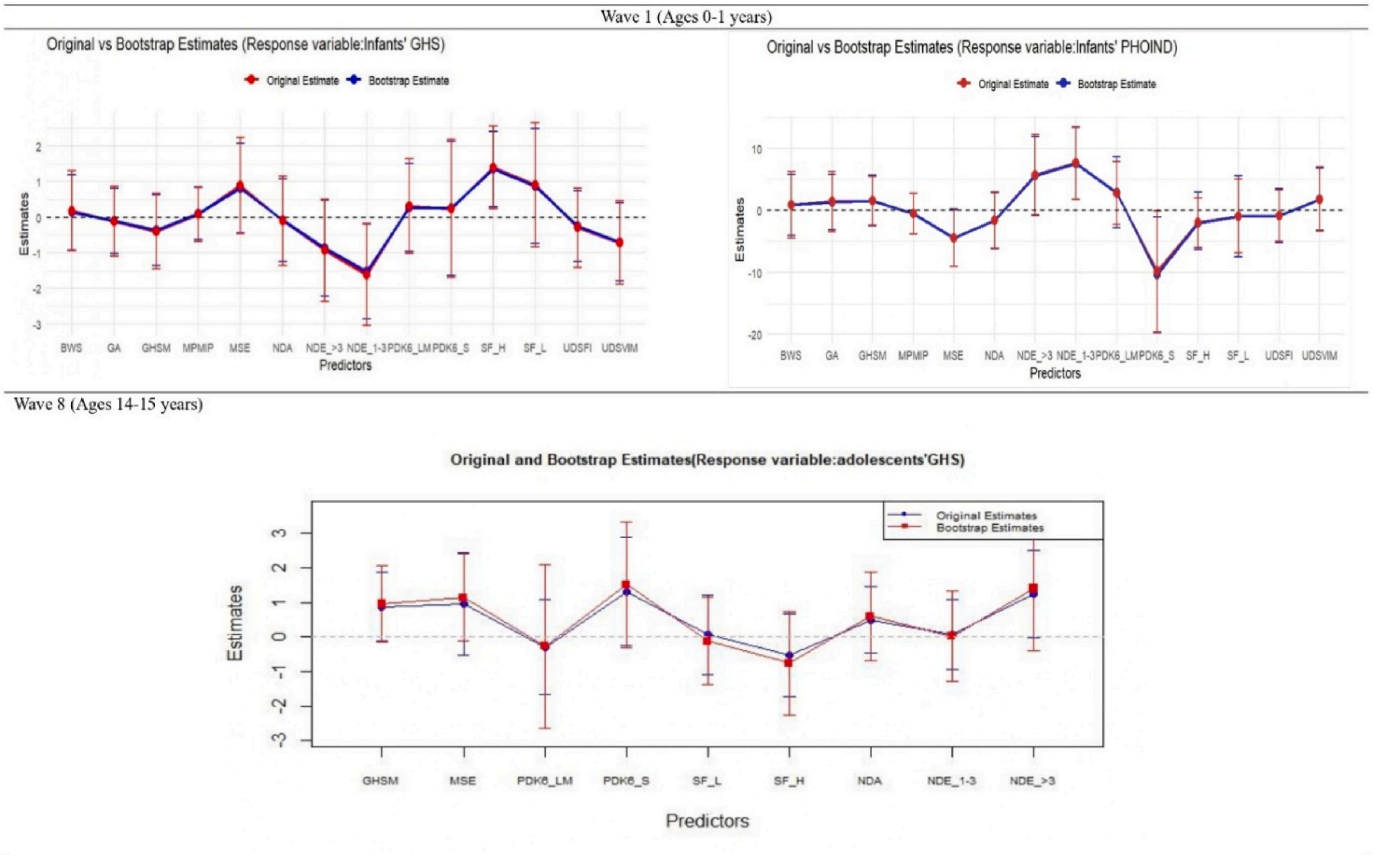
heavy smokers. As children transitioned into adolescence, similar trends were observed in maternal health behaviors, with notable differences between waves. Among mothers of Indigenous adolescents, 36.5 % smoked, with 16.2 % being light smokers and 20.3 % being heavy smokers. In contrast, only 9.3 % of non-Indigenous mothers of adolescents smoked, including 5.5 % light smokers and 3.8 % heavy smokers. Alcohol consumption was higher among non-Indigenous mothers (31.3 %) compared to Indigenous mothers (16.9 %) during infancy. This rate rose to 27.0 %, highlighting an increase from the infant stage among mothers of Indigenous adolescents.

Mothers of non-Indigenous infants were more likely to engage in healthier behaviors, with 48.5 % participating in at least 30 min of exercise 1–3 days per week, compared to 38.9 % of Indigenous mothers. This pattern continued into adolescence at slightly reduced levels, with 45.5 % of mothers of non-Indigenous adolescents engaging in regular exercise, compared to 43.2 % of mothers of Indigenous adolescents. A higher percentage of mothers of non-Indigenous infants consumed vegetables (79.3 %) and fruits (67.2 %) daily compared to mothers of Indigenous infants.

3.1. *Impact of maternal health, health-related behaviors, and risk factors on child health outcomes*

Fig. 2 compares the original and bootstrap estimates of GHS and the PHOIND scores for Indigenous infants, while for adolescents, the comparison is made only for GHS. Bootstrap estimates were computed by repeated sampling with replacement from the observed data considering the estimate for each resampled dataset. This method helps to assess the estimates' stability and reliability, particularly when the sample size is small (Picheny et al., 2010). In this study, original and bootstrap estimates of GHS (for both infants and adolescents) and the PHOIND score (for infants) are observed to be very close to each other (Fig. 2).

This similarity ensures that the estimates are stable and reliable despite the modest sample size, indicating that the small sample size does not significantly affect the accuracy of the estimates. Therefore, even though the Indigenous sample size is small, the strong agreement between the original and bootstrap estimates implies that this sample is representative of the Indigenous population. As a result, comparisons between Indigenous and non-Indigenous participants are valid, meaning that any observed differences between these groups are likely to reflect



GHSM-General health status of the mother; MPMIP-Mothers having any prescribed medicines in pregnancy; MSE-Mothers' SLE in the year before the interview;PDK6_LM-Psychological distress (Low to moderate); PDK6_S-Psychological distress (Severe); SF_L-Smoking frequency (Light smoker); SF_H-Smoking frequency (Heavy smoker); NDA-Number of days per week alcohol was consumed;NDE_1-3-Number of days in a week mothers engage in exercise (1-3 days); NDE_>3-Number of days in a week mothers engage in exercise (> 3 days); UDSVIM-Usual daily serves of vegetable intake; UDSFI-Usual daily serves of fruit intake; BWS-Birth weight of study child (> 2500gm); GA-Gestational age (> 37 weeks);GHS-General health status; PHOIND-Physical health outcome index.

Fig. 2. Comparison of original and bootstrap estimates for infants' (GHS and PHOIND) and adolescents (GHS).

true disparities rather than being artefacts of sampling variability.

Table 2 presents the associations between maternal health factors and the likelihood of infants having LOPTH, highlighting differences between Indigenous and non-Indigenous populations. Among Indigenous infants, maternal smoking, particularly heavy smoking (≥10 cigarettes per day), was strongly associated with increased odds of LOPTH (3.91, 95 %CI: 1.33, 11.49), whereas this association was not statistically significant for non-Indigenous infants (Table 2).

Maternal physical activity during pregnancy demonstrated a protective effect. Among Indigenous infants, mothers who exercised one to three days per week had significantly lower odds of the LOPTH (OR = 0.22, 95 % CI: 0.06, 0.83, $p = 0.016$), suggesting that even moderate physical activity can positively influence infant health. A similar protective trend was observed among non-Indigenous infants (OR = 0.74, 95 % CI: 0.58, 0.95, $p = 0.017$), though the effect was slightly weaker. Maternal dietary habits, particularly vegetable intake, also played an important role. Among non-Indigenous infants, mothers who consumed vegetables at least once daily had lower odds of LOPTH (OR = 0.77, 95 % CI: 0.57, 1.05, $p = 0.091$), although the association was statistically significant at 10 % level.

Table 3 shows the impact of maternal health factors on the PHOIND score for infants. Maternal physical activity was again beneficial, with Indigenous infants whose mothers exercised one to three days per week having significantly higher the PHOIND scores ($\widehat{\beta} = 7.56$, 95 % CI: 1.76, 13.36, $p = 0.010$). A similar effect was observed among non-Indigenous infants ($\widehat{\beta} = 1.36$, 95 % CI: 0.53, 2.19, $p = 0.001$), reinforcing the positive role of maternal exercise on infant physical health. Birth weight was another significant factor for non-Indigenous infants, where those with a birth weight above 2500 g had significantly higher the PHOIND scores ($\widehat{\beta} = 1.68$, 95 % CI: 0.26, 3.09, $p = 0.019$).

An analogous association was found for gestational age, as non-Indigenous infants born after 37 weeks had higher the PHOIND scores ($\widehat{\beta} = 1.58$, 95 % CI: 0.62, 2.54, $p = 0.001$). However, for Indigenous infants, neither birth weight nor gestational age was significantly associated with the PHOIND scores, indicating that other determinants may be more influential in shaping their physical health outcomes.

Additionally, mothers of Indigenous infants who experienced at least one SLEs in the year before the interview had infants with a lower PHOIND score ($\widehat{\beta} = -4.45$, 95 % CI: 9.09, 0.19, $p = 0.060$), though the association was only marginally significant. Severe psychological distress among mothers in this group was also significantly associated with a lower PHOIND score ($\widehat{\beta} = -10.37$, 95 % CI: 19.73, −1.02, $p = 0.030$). However, these associations were not significant for the non-Indigenous group. Maternal LOPTH was highly statistically significantly associated with a lower PHOIND score for non-Indigenous infants ($\widehat{\beta} = -2.83$, 95 % CI: 3.47, −2.18, $p < 0.001$), suggesting that maternal LOPTH is associated with worse infant PHOIND among the non-Indigenous group.

Furthermore, taking prescribed medicines during pregnancy was significantly associated with a negative effect on infant physical health among the non-Indigenous group ($\widehat{\beta} = -1.29$; 95 % CI: 1.91, −0.68; $p < 0.001$), indicating that the use of prescribed medicines in pregnancy is linked to worse PHOIND scores for non-Indigenous infants. However, this association was not significant for the Indigenous group.

Table 4 reveals the associations between various maternal health-related factors and the risk of adolescents having LOPTH. Maternal poor health was highly significantly associated with an increased risk of the LOPTH among non-Indigenous adolescents ($\widehat{\beta} = 1.10$, 95 % CI:2.40, 3.83, $p < 0.001$), indicating adolescents whose mothers have poor health are more than three times as likely to experience the LOPTH compared to those with mothers in OPTH. Moreover, severe psychological distress and smoking status were also associated with a higher risk of the LOPTH among non-Indigenous adolescents. However, no significant associations were observed for the Indigenous group, despite some elevated odds ratios.

Table 2
Maternal health and health-related behaviors and their associations with Indigenous and non-indigenous infant's general health status.

Risk of having LOPTH among Infants						
	Indigenous; ($n = 210$)			Non-Indigenous; ($n = 4537$)		
	$\widehat{\beta}$ (SE)	*p*-value	OR (95 % CI)	$\widehat{\beta}$ (SE)	*p*-value	OR (95 % CI)
General health status of the mother [OPTH (ref.)]						
LOPTH	−0.36 (0.51)	0.482	0.69 (0.25, 1.92)	0.92 (0.10)	<0.001	2.52*** (2.07, 3.08)
Mothers having any prescribed medicines in pregnancy [No (ref.)]						
Yes	0.11 (0.37)	0.775	1.11 (0.53, 2.32)	0.25(0.09)	0.009	1.29***(1.06, 1.56)
Mothers' SLE in the year before the interview [No event (ref.)]						
Yes (1 or more event)	0.82 (0.64)	0.201	2.29 (0.64, 8.18)	0.01(0.10)	0.971	1.01(0.81, 1.25)
Psychological distress [No psychological distress (ref.)]						
Low to moderate psychological distress	0.28 (0.63)	0.653	1.32 (0.38, 4.61)	0.15(0.15)	0.313	1.16(0.87, 1.56)
Severe psychological distress	0.25 (0.96)	0.791	1.29 (0.19, 8.58)	−0.01(-0.34)	0.976	0.99(0.50, 1.94)
Smoking frequency [None (ref.)]						
Less than 10/day (Light smoker)	0.87 (0.82)	0.293	2.38 (0.47, 12.09)	0.10(0.21)	0.605	1.11(0.74, 1.67)
More than or equal 10/day (Heavy smoker)	1.36 (0.54)	0.013	3.91** (1.33, 11.49)	0.03(0.15)	0.844	1.03(0.76, 1.39)
Number of days per week alcohol was consumed [Never/rarely (ref.)]						
Once or more in a week	−0.08 (0.59)	0.886	0.92 (0.28, 2.96)	−0.02(-0.10)	0.774	0.97 (0.79, 1.19)
Number of days in a week mothers engage in at least 30 min of exercise [None (0 days) (ref.)]						
1–3 days/week	−1.53(0.68)	0.016	0.22* (0.06, 0.83)	−0.30(-0.13)	0.017	0.74**(0.58, 0.95)
More than 3 days/week	−0.87 (0.69)	0.207	0.42 (0.11, 1.63)	−0.21 (−0.15)	0.150	0.81(0.60, 1.08)
Usual daily serves of vegetable intake by mother [Never/rarely (ref.)]						
One or more times/day	−0.69 (0.56)	0.214	0.50 (0.17, 1.49)	−0.26(-0.16)	0.091	0.77*(0.57, 1.05)
Usual daily serves of fruit intake by mother [Never/rarely (ref.)]						
One or more times in a day	−0.25 (0.51)	0.632	0.78 (0.28, 2.13)	−0.06 (−0.12)	0.590	0.93 (0.73, 1.19)
Birth weight of study child [Less than 2500gm (ref.)]						
>2500gm	0.14 (0.54)	0.789	1.15 (0.39, 3.39)	−0.22 (−0.20)	0.270	0.80(0.53, 1.19)
Gestational age [≤37 weeks (ref.)]						
>37 weeks	−0.10 (0.47)	0.831	0.90 (0.35, 2.30)	−0.17 (−0.15)	0.254	0.84(0.63, 1.13)

Note: OPTH-optimal health; LOPTH-less-optimal health; *** for 1 % level of significance; ** for 5 % level of significance; * for 10 % level of significance; SE - standard error; OR-odds ratio; $\widehat{\beta}$ is the estimated regression coefficient.

Table 3
Maternal health and health-related behaviors and their associations with Indigenous and non-Indigenous infant's physical health outcome index score.

	Physical health outcome index (PHOIND) score (for infant age 0–1 year)					
	Indigenous (n = 210)			Non-Indigenous (n = 4537)		
	$\widehat{\beta}$ (95 % CI)	SE	p-value	$\widehat{\beta}$ (95 % CI)	SE	p-value
General health status of the mother [OPTH (ref.)]						
LOPTH	1.60 (−2.45, 5.65)	2.05	0.436	−2.83*** (-3.47, −2.18)	0.32	<0.001
Mothers having any prescribed medicines in pregnancy [No (ref.)]						
Yes	−0.51 (−3.76, 2.74)	1.65	0.758	−1.29*** (-1.91, −0.68)	0.31	<0.001
Mothers' SLE in the year before the interview [No event (ref.)]						
Yes (1 or more event)	−4.45* (-9.09, 0.19)	2.35	0.060	−0.40 (−1.02, 0.21)	0.31	0.204
Psychological distress [No psychological distress (ref.)]						
Low to moderate psychological distress	2.88 (−2.87, 8.65)	2.92	0.326	−0.46 (−1.50, 0.58)	0.53	0.385
Severe psychological distress	−10.37* (-19.73, −1.02)	4.74	0.030	−0.36 (−2.7, 2.03)	1.22	0.764
Smoking frequency [None (ref.)]						
Less than 10/day (Light smoker)	−0.97 (−7.54, 5.60)	3.33	0.771	0.77 (−0.59, 2.13)	0.69	0.267
More than or equal 10/day (Heavy smoker)	−2.02 (−6.34, 2.92)	2.18	0.354	0.76 (−0.23, 1.75)	0.50	0.132
Number of days per week alcohol was consumed [Never/rarely (ref.)]						
once or more in a week	−1.63 (−6.18, 2.92)	2.31	0.481	0.01 (−0.61, 0.63)	0.30	0.971
Number of days in a week mothers engage in at least 30 min of exercise [None (0 days) (ref.)]						
1–3 days/week	7.56** (1.76, 13.36)	2.94	0.010	1.36** (0.53, 2.19)	0.42	0.001
more than 3 days/week	5.61* (−0.69, 11.93)	3.20	0.080	1.40** (0.44, 2.34)	0.47	0.003
Usual daily serves of vegetable intake by mother [Never/rarely (ref.)]						
One or more times/day	1.74 (−3.25, 6.74)	2.53	0.492	0.81 (−0.24, 1.87)	0.53	0.133
Usual daily serves of fruit intake by mother [Never/rarely (ref.)]						
one or more times in a day	−0.81 (−5.18, 3.55)	2.21	0.713	0.02 (−0.77, 0.82)	0.40	0.952
Birth weight of study child [Less than 2500gm (ref.)]						
>2500gm	0.89 (−4.06, 5.85)	2.51	0.722	1.68** (0.26, 3.09)	0.71	0.019
Gestational age [≤37 weeks (ref.)]						
>37 weeks	1.33 (−3.09, 5.76)	2.44	0.553	1.58*** (0.62, 2.54)	0.48	0.001

Note: OPTH-optimal general health; LOPTH-less-optimal general health; *** for 1 % level of significance; ** for 5 % level of significance; * for 10 % level of significance; SE - standard error; $\widehat{\beta}$ is the estimated regression coefficient.

3.2. Longitudinal associations between wave 1 predictors and wave 8 outcomes

To leverage the longitudinal design of the LSAC dataset, we examined associations between maternal and perinatal factors measured at Wave 1 and adolescent General Health Status (GHS) at Wave 8 (Supplementary Tables 1 and 2). Among non-Indigenous adolescents, several early maternal health indicators were significantly associated with a higher proportion of adolescents reporting less-optimal health (LOPTH) at Wave 8. As shown in Supplementary Table 1, adolescents whose mothers reported less-optimal general health had a higher prevalence of LOPTH (22.1 %) compared to those whose mothers reported optimal health (11.5 %, $p < 0.001$). Similar patterns were observed for other early risk factors, including maternal prescribed medication use during pregnancy (18.3 % vs. 13.4 %, $p = 0.002$), experience of stressful life events (16.8 % vs. 12.4 %, $p = 0.001$), severe psychological distress (25.8 % vs. 14.3 %, $p = 0.022$), heavy maternal smoking (23.6 % vs. 14.0 %, $p = 0.001$), lower exercise frequency (18.4 % for no exercise vs. 13.7 % for >3 days/week, $p = 0.017$), lower fruit intake (17.5 % vs. 13.9 %, $p = 0.023$), and preterm birth (22.6 % vs. 13.9 %, $p < 0.001$).

In contrast, for Indigenous adolescents, only maternal prescribed medication use during pregnancy showed a statistically significant association with adolescent LOPTH (38.2 % vs. 17.5 %, $p = 0.04$). Although other risk factors such as maternal stressful life events, psychological distress, smoking, and poor dietary habits were associated with higher proportions of LOPTH among Indigenous adolescents, these associations did not reach statistical significance, likely due to limited sample size (n = 74).

Supplementary Table 2 presents the results from multivariable logistic regression analyses estimating the strength of these associations. Consistent with prevalence patterns, among non-Indigenous adolescents, maternal LOPTH (OR = 1.99, $p < 0.001$), prescribed medicine use during pregnancy (OR = 1.28, $p = 0.037$), maternal stressful life events (OR = 1.39, $p = 0.005$), and heavy smoking (OR = 1.50, $p = 0.030$) were significantly associated with increased odds of adolescent LOPTH. Preterm birth was associated with decreased odds of optimal adolescent health (OR = 0.58, $p = 0.003$). For Indigenous adolescents, similar trends were observed—particularly higher odds of LOPTH with maternal prescribed medication use (OR = 2.79, $p = 0.089$) and severe psychological distress (OR = 8.58, $p = 0.226$)—but these associations were not statistically significant, again likely due to limited statistical power.

4. Discussion

This study examined the associations between maternal health, health-related behaviors, and child health outcomes among Indigenous and non-Indigenous Australian children across infancy and adolescence. By using bootstrap estimation to address the methodological challenges posed by small Indigenous sample sizes, the study highlights persistent and widening disparities in maternal and child health across developmental stages. These findings underscore the urgent need for culturally responsive, early interventions to improve health equity for Indigenous families.

Using nationally representative LSAC data, results show that Indigenous infants and adolescents were more likely to experience less optimal health (LOPTH) compared to non-Indigenous peers. Notably, the disparity widened from infancy to adolescence, suggesting that health inequalities not only persist but intensify over time. This aligns with life course epidemiological frameworks that emphasize the cumulative impact of early life exposures such as maternal health, prenatal behavior, and perinatal conditions on long-term child health outcomes (Gracey and King, 2009; Shepherd et al., 2012; Zubrick et al., 2014).

A key contribution of this study lies in its longitudinal design, spanning infancy (Wave 1) to adolescence (Wave 8), offering novel insights beyond cross-sectional associations. The longitudinal analysis demonstrates that early maternal health disadvantages predict poor adolescent health, particularly for non-Indigenous participants. This temporal linkage strengthens the evidence for a life-course pattern of intergenerational disadvantage and highlights the importance of maternal health in shaping adolescent outcomes. This highlights the

Table 4
Maternal health and health-related behaviors and their associations with Indigenous and non-indigenous adolescent's general health status.

Risk of having LOPTH among adolescents (Aged 14–15 years)						
	Indigenous; ($n = 74$)			Non-Indigenous; ($n = 2727$)		
	$\widehat{\beta}$ (SE)	*p*-value	OR (95 % CI)	$\widehat{\beta}$ (SE)	*p*-value	OR (95 % CI)
General health status of the mother [Good health (ref.)]						
Poor health	0.87 (0.60)	0.153	2.39 (0.73, 7.83)	1.10***(0.11)	<0.001	3.03 (2.40, 3.83)
Mothers' SLE in the year before the interview [No event (ref.)]						
Yes (1 or more event)	0.94 (0.89)	0.283	2.58 (0.44, 15.02)	0.08 (0.13)	0.528	1.09 (0.83, 1.44)
Psychological distress [No psychological distress (ref.)]						
Low to moderate psychological distress	−0.29 (0.83)	0.735	0.74 (0.14, 3.85)	0.40** (0.16)	0.014	1.49 (1.09, 2.06)
Severe psychological distress	1.30 (0.95)	0.168	3.69 (0.57, 23.77)	0.41 (0.30)	0.191	1.50 (0.83, 2.74)
Smoking frequency [None (ref.)]						
Less than 10/day (Light smoker)	0.05 (0.70)	0.936	1.06 (0.26, 4.25)	0.45** (0.20)	0.029	1.57 (1.10, 2.33)
More than or equal 10/day (Heavy smoker)	−0.52 (0.72)	0.477	0.59 (0.14, 2.45)	0.47* (0.23)	0.053	1.60 (1.01, 2.55)
Number of days per week alcohol was consumed [Never/rarely (ref.)]						
Once or more in a week	0.49 (0.59)	0.419	1.64 (0.51, 5.22)	−0.20 (0.13)	0.061	0.82 (0.63, 1.05)
Number of days in a week mothers engage in at least 30 min of exercise [None (0 days) (ref.)]						
1–3 days/week	0.07 (0.62)	0.914	1.07 (0.31, 3.63)	−0.03 (0.12)	0.782	0.96 (0.75, 1.23)
More than 3 days/week	1.24 (0.77)	0.112	3.47 (0.76, 15.70)	0.10 (0.15)	0.502	1.11 (0.82, 1.51)

Note: OPTH-optimal health; LOPTH-less-optimal health; *** for 1 % level of significance; ** for 5 % level of significance; * for 10 % level of significance; SE - standard error; OR-odds ratio; $\widehat{\beta}$ is the estimated regression coefficient.

critical need for sustained maternal health support throughout a child's life course, particularly for disadvantaged populations, to mitigate the long-term effects of early health behaviors on child and adolescent development. For Indigenous adolescents, while most associations did not reach statistical significance (likely due to sample size), consistent non-significant trends suggest the enduring impacts of early maternal adversity. This added longitudinal component advances the field by showing that early health exposures not only correlate with concurrent outcomes but also predict future health trajectories.

Maternal LOPTH in the year following childbirth was associated with higher odds of LOPTH among non-Indigenous infants and adolescents, and with lower PHOIND scores in infancy. In Indigenous participants, similar trends were observed but not statistically significant, likely reflecting cultural, systemic, or access-related differences (Callander et al., 2022). Longitudinal analysis further revealed that maternal LOPTH, medication use during pregnancy, exposure to stressful life events (SLEs), psychological distress, smoking, low physical activity, poor diet, and preterm birth were all associated with adolescent LOPTH among non-Indigenous youth. Among Indigenous adolescents, only maternal medication use was statistically significant, but other factors followed consistent patterns, reinforcing the hypothesis of intergenerational health risks.

Mothers of Indigenous infants were less likely to engage in health-promoting behaviors such as regular exercise or consuming fruits and vegetables. These behaviors were linked to better infant health across both groups. Additionally, maternal smoking significantly increased LOPTH risk among Indigenous infants, consistent with prior research (Miyake et al., 2013; Wehby et al., 2011). Maternal psychological distress and SLEs during pregnancy were significantly associated with lower PHOIND scores for Indigenous infants, but not for non-Indigenous ones indicating possible heightened vulnerability among Indigenous children to maternal mental health challenges (Meredith et al., 2023).

During adolescence, maternal distress and life stressors were elevated in both groups, with a higher prevalence among Indigenous mothers. Yet only among non-Indigenous adolescents did these maternal mental health challenges associate with adolescent GHS. This discrepancy may reflect culturally embedded protective factors, such as Indigenous resilience, broader definitions of health, or other community-based support mechanisms.

Our findings also highlight notable changes in maternal health behaviors over time, including declines in smoking rates and increases in psychological distress, particularly among Indigenous mothers. These shifts in maternal health may reflect broader social and structural inequities that persist across generations. Although our study design limited our ability to track individual-level changes due to inconsistent data formats and attrition, the observed group-level trends suggest that persistent maternal health risks, especially behaviors like smoking and psychological distress, may have cumulative impacts on adolescent health outcomes. This highlights the critical need for sustained maternal health support throughout a child's life course, particularly for disadvantaged populations, to mitigate the long-term effects of early health behaviors on child and adolescent development.

A major strength of this study is the use of bootstrap resampling to validate findings, which helped counter limitations from small Indigenous samples and increased the stability of estimates (Dwivedi et al., 2017; Walters and Campbell, 2004). The close agreement between original and bootstrap results supports the robustness of associations and allows more confident interpretation despite inherent data challenges.

While our longitudinal analysis links maternal exposures in infancy to adolescent health outcomes, future research should further leverage LSAC's design. Advanced methods such as growth curve modeling, or trajectory analysis could identify distinct developmental patterns and more precisely characterize subgroups at risk. These approaches could deepen our understanding of how early exposures differentially shape health outcomes over time and reveal more nuanced policy levers for intervention.

The findings have clear implications for public health policy. Given the sustained disparities observed, early intervention strategies co-designed with Indigenous communities are essential. These strategies should integrate culturally safe care models, increase Indigenous workforce participation in healthcare, and support family-centered approaches aligned with Indigenous definitions of health. Interventions should include maternal mental health support, anti-smoking programs, physical activity promotion, and nutritional guidance, while also addressing broader structural barriers such as housing, education, and systemic racism. Sustainable, community-led strategies are necessary to disrupt intergenerational disadvantage and reduce the widening health gap between Indigenous and non-Indigenous Australians.

4.1. Limitations

This study provides valuable insights into the relationship between maternal health and child outcomes; however, several limitations

should be acknowledged. A primary limitation is the high attrition rate observed between Wave 1 and Wave 8, which may have reduced the statistical power to detect significant associations, particularly within the Indigenous group, potentially limiting the generalizability of the findings. Additionally, the study relied on self-reported data for maternal health behaviors and outcomes, which may be subject to recall bias or social desirability bias. A specific concern relates to the use of self-reported health outcomes during infancy, where both maternal and infant health were reported by the mother. However, adolescent health outcomes were self-reported, reducing shared informant bias. Including both subjective (e.g., GHS) and composite (e.g., PHOIND) outcomes helped mitigate reliance on single-source measures. While bootstrap resampling was employed to improve the stability of estimates for the Indigenous group, the small sample size still introduces a degree of uncertainty, as reflected in wider confidence intervals. Furthermore, inconsistencies in variable availability across waves constrained the scope of more comprehensive longitudinal analyses. Nevertheless, the supplementary analyses linking Wave 1 maternal and perinatal predictors to Wave 8 adolescent outcomes provided a valuable, albeit partial, means of addressing this limitation. Future research should prioritize larger Indigenous samples, more comprehensive data collection, and the inclusion of broader contextual factors to deepen understanding of the determinants of child health outcomes.

5. Conclusions

This study highlights significant health disparities between Indigenous and non-Indigenous Australian children from infancy to adolescence, with Indigenous children consistently experiencing less-optimal health (LOPTH) outcomes. Maternal health, including psychological distress and behaviors such as smoking and physical activity, plays a crucial role in shaping these outcomes. Indigenous mothers reported higher levels of psychological distress, more stressful life events (SLEs), and lower engagement in healthy behaviors, contributing to the compounded health inequalities observed over time. By applying bootstrap estimation techniques, the study addresses the challenges posed by small Indigenous sample sizes, ensuring robust comparisons. The findings emphasize the urgent need for culturally tailored, community-led interventions to address these disparities and promote health equity for Indigenous families. Despite ongoing policy initiatives, structural and social factors continue to drive child health inequalities. To effectively reduce these disparities, it is vital to implement targeted policies and expand culturally appropriate healthcare services to address both immediate needs and long-term systemic inequalities.

CRediT authorship contribution statement

Nahida Afroz: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Enamul Kabir:** Writing – review & editing, Supervision, Conceptualization. **Khorshed Alam:** Writing – review & editing, Supervision. **Zakir Hossain:** Writing – review & editing, Methodology.

Consent to participate

Since the secondary data utilized in this study did not contain any identifiable information, consent for participation was not required.

Ethics approval

The LSAC study received ethical approval from the Australian Institute of Family Studies Ethics Committee. The dataset was accessed through the Longitudinal Study of Australian Children Dataverse of the National Centre for Longitudinal Data. Researchers are permitted to use this dataset in compliance with national regulations, provided that no identifiable individual information is included.

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Declaration of competing interest

The authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.socscimed.2025.118292.

Data availability

Data will be made available on request.

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