ORIGINAL RESEARCH

Determinants of rapid infant weight gain: A pooled analysis of seven cohorts

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Summary

Objective: Rapid weight gain (RWG) in infancy is strongly associated with subsequent obesity risk, but little is known about the factors driving RWG. This study explored the child and maternal factors associated with infant RWG.

Methods: Data from seven Australian and New Zealand cohorts were used (n = 4542). Infant RWG was defined as a change in weight z-score ≥0.67 from birth to age 1 year. Univariable and multivariable logistic regression assessed the association between child and maternal factors and infant RWG in each cohort. Meta-analysis was conducted to obtain pooled effect sizes.

Results: Multivariable analyses revealed boys were more likely to experience RWG (OR 1.42 95% CI 1.22, 1.66) than girls. Higher birth weight in kg (OR 0.09, 95% CI 0.04, 0.20) and gestational age in weeks (OR 0.69, 95% CI 0.48, 0.98) were associated with lower RWG risk. Children who were breastfed for ≥6 months showed lower RWG risk (OR 0.45, 95% CI 0.38, 0.53). Children of native-born versus overseas-born women appeared to have higher RWG risk (OR 1.37, 95% CI 0.99, 1.90). Maternal smoking during pregnancy increased RWG risk (OR 1.60, 95% CI 1.28, 2.01), whereas children who started solids ≥6 months (OR 0.77, 95% CI 0.63, 0.93) and children with siblings (OR 0.68, 95% CI 0.57, 0.81) showed lower RWG risk in univariable analysis,

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Abbreviations: BIS, Barwon Infant Study; BMI, body mass index; HB, Healthy Beginnings; InFANT, Infant Feeding Activity and Nutrition Trial; RWG, rapid weight gain; WHO, World Health Organization.

but these associations were attenuated in multivariable analysis. No association was found for maternal age, education, marital status and pre-pregnancy BMI.
Conclusion: Maternal country of birth, smoking status, child sex, birth weight, gestational age, infant feeding and parity were potential determinants of infant RWG.

KEYWORDS
birth weight, determinants, infant, infant feeding, pooled analysis, rapid weight gain

1 | INTRODUCTION

Rapid weight gain (RWG) in infancy has been associated with an array of adverse health outcomes.[1,2] Systematic reviews have consistently shown a positive association between infant RWG and subsequent higher obesity risk with two- to threefold elevation in risk.[3-5] Emerging evidence has also linked infant RWG with other major risk factors of chronic diseases such as glucose intolerance, hypertension and dyslipidaemia.[6]

Infant RWG can serve as a useful intermediate/surrogate marker for early detection of later obesity and associated adverse health outcomes. Prevention and early identification of RWG during infancy provide an important opportunity for optimizing lifelong health. RWG from birth to 1 year of age is more strongly linked to risk of subsequent obesity than RWG from birth to 2 years of age,[5] highlighting the 1st year of life as a critical period for primary prevention.

Despite extensive research highlighting the detrimental effect of infant RWG on later health outcomes, examination of the determinants of RWG during infancy is scarce.[7] The existing studies are limited to reporting factors associated with RWG in early childhood from birth to 2 years of age and focus on studying one or two factors of interest (e.g. infant feeding or maternal smoking).[7] However, as infant RWG is likely influenced by a broad range of factors, understanding how each predicts infant RWG can inform risk prediction and targeted prevention strategies.

Therefore, this study aimed to examine the association between a number of maternal and child factors in the prenatal and postnatal period and RWG during infancy across seven Australian and New Zealand cohorts. By using a uniform analysis approach, results for each factor were summarized and synthesized.

2 | METHODS

2.1 | Study design and cohorts

The present study included seven Australian and New Zealand cohorts: BIS (Barwon Infant Study),[8] HB (Healthy Beginnings),[9-11] INFANT (Infant Feeding Activity and Nutrition Trial),[12,13] INFANT Extend,[14] LIMIT,[15,16] NOURISH[17,18] and POI.[19,20] The cohort characteristics are shown in Table 1. BIS is a population-based birth cohort, and all other cohorts are randomized controlled trials (RCTs) that aimed to prevent obesity in early childhood. Of the six RCTs, five

included women in their first (HB, INFANT, INFANT EXTEND and NOURISH) or any (POI) pregnancies with no restrictions on maternal body mass index (BMI). LIMIT recruited pregnant women with BMI ≥25 kg/m². Baseline recruitment was undertaken either antenatally or postnatally from 2007 to 2013. All seven cohorts assessed anthropometrics at birth and at follow-up around 1 year of age (ranged from ages 7.0 to 13.6 months) and collected various maternal and child factors throughout this time. Ethical approval for each study was obtained from relevant institutional ethics committees and informed written consent from participants was obtained.

2.2 | Rapid weight gain during infancy

Across seven cohorts, child length and weight at birth were transcribed from child health records. Child length and weight around 1 year of age were measured using standard protocols by trained staff. WHO growth standards[21] were used to calculate age- and sex-specific weight-for-age z-scores at birth and the follow-up, and the difference between the time points was calculated. Rapid weight gain was defined as a change in weight for age z-score ≥0.67, which is clinically equivalent to crossing one centile line in a growth chart.[5,22]

2.3 | Maternal and child factors

A range of maternal and child factors were collected across the cohorts. The following maternal factors were assessed: country of birth (native born vs. overseas born), education level (tertiary education vs. non-tertiary education), marital status (married vs. not married), smoking status (smoker vs. non-smoker) and pre- or early pregnancy BMI (kg/m²). Child factors included sex (boys vs. girls), birth weight (kg), any breastfeeding duration (<6 vs. ≥6 months), timing of solid introduction (before <6 vs. at or after ≥6 months), parity (≥1 sibling vs. no sibling) and gestational age (weeks). Intervention allocation was also assessed as a determinant in six RCTs. Additional analyses were conducted to evaluate categorical forms of maternal pre-pregnancy BMI (healthy weight <25 kg/m² vs. overweight 25–30 kg/m² vs. obesity ≥30 kg/m²), child birth weight (low/normal <4 kg vs. high ≥4 kg) and gestational age (pre-term <37 weeks vs. full term ≥37 weeks) as determinants of infant RWG. Due to the small number of low birth weight children (1.2%–6.9%), they were combined with normal weight children for analyses. Variables collected in ≥2

TABLE 1 Study characteristics of the seven cohorts: analysis of determinants of rapid weight gain during infancy

	BIS	HB	INFANT	INFANT EXTEND	LIMIT	NOURISH	POI
Study design	Population-based birth cohort	RCT	Cluster RCT	Cluster RCT	RCT	RCT	RCT
Year at baseline	2010–2013	2007	2008	2011–2012	2008–2011	2008–2009	2009–2010
Participants	Pregnant women and their infants	First time mothers and their infants	First time mothers and their infants	First time mothers and their infants	Pregnant women with BMI≥25 and their infants	First time mothers and their infants	Pregnant women and their infants
Location	Geelong, Australia	Southwest Sydney, Australia	Melbourne, Australia	Melbourne, Australia	Adelaide, Australia	Brisbane and Adelaide, Australia	Dunedin, New Zealand
Baseline recruitment	15-week gestation	24–34-week gestation	Infants aged 3–4 months	Infants aged 3–4 months	10–20-week gestation	Infants aged 4–7months	28–30-week gestation
Intervention	n/a	Infant feeding, family nutrition, physical activity	Infant feeding, physical activity, sedentary behaviours	Infant feeding, physical activity, sedentary behaviours	Lifestyle advice on diet and exercise for pregnant women	Infant feeding	Infant feeding, physical activity, sleep
Age at the follow-up (Mean ± SD, months)	13.0 ± 0.8	12.2 ± 0.8	9.2 ± 1.1	9.6 ± 2.2	7.0 ± 1.9	13.6 ± 1.3	12.2 ± 0.3
Participants at baseline (n)	1074	667	542	514	2126	698	802
Participants lost to follow-up (n)	200	190	27	136	379	132	126
Participants with missing covariates (n)	158	33	32	118	281	45	24
Participants included in the final analysis (n)	716	444	483	260	1466	521	652

Abbreviations: BIS, Barwon Infant Study; HB, healthy beginnings; INFANT Extend, Infant Feeding Activity and Nutrition Trial Extend; INFANT, Infant Feeding Activity and Nutrition Trial; POI, prevention of obesity in infancy trial.

cohorts were examined as determinants for infant RWG. All determinants were coded consistently across the seven cohorts to enable comparison and meta-analysis to obtain pooled effects.

2.4 | Statistical analysis

All analyses were conducted in Stata 16 with statistical significance set at $p < 0.05$ (two sided). A descriptive analysis of cohort characteristics was conducted. Analyses were performed to compare the cohort characteristics of those retained and excluded from the current analysis. We conducted separate analyses in each cohort using a consistent analysis approach. As some factors (e.g. child birth weight) may underlie the causal pathways between other factors (e.g. maternal smoking, parity) and RWG, both univariable and multivariable logistic regression analyses were conducted. Univariable logistic regression with infant RWG as the outcome and each maternal and child variable and intervention allocation as the exposure were initially conducted. All maternal and child variables were then included simultaneously in the same multivariable logistic regression model to assess the respective association with infant RWG. Pearson correlations were performed to determine multicollinearity amongst all maternal and child variables. For variables that showed high correlation, the variable that exhibited the stronger association with infant RWG was included in the final multivariable model along with other factors. Child birth weight and gestational age showed a correlation of $r > 0.5$ across all cohorts, and child birth weight showed a stronger association with infant RWG. No correlations were found for other maternal and child factors. Thus, the final multivariable model included all child and maternal variables except for gestational age. Variables included in the final multivariable model for each cohort are presented in Table S1. The adjusted odds ratio for the association between gestational age and infant RWG was investigated in a separate multivariable model excluding child birth weight. The odds ratios (95% confidence interval) of each variable from univariable and multivariable models were included in a subsequent meta-analysis. I^2 statistics were used to evaluate heterogeneity across the cohorts. For variables that showed the presence of heterogeneity across studies (I^2 value >50%, $p < 0.1$), a random-effects meta-analysis was conducted to calculate the pooled effect size. Fixed effect meta-analysis was used to obtain pooled effect size for variables exhibiting no heterogeneity across studies.

2.5 | Additional analyses

For variables that showed discrepant results between univariable and multivariable models, meditation analyses were conducted to identify potential mediating effects using the 'PARAMED' command. Indirect (mediating) effects from the multivariable model were estimated in each study and meta-analyses were performed to obtain pooled indirect effects.

Considering the variability in length of follow-up across studies, additional analyses excluding three cohorts (INFANT, INFANT Extend and LIMIT) that involved follow-up before age 12 months were also conducted. This additional analysis also tests whether excluding children of women with overweight and obesity from the LIMIT trial influence the pooled effects.

To test the impact of missing covariates on the analyses, multiple imputations by chained equations with 10 data sets were conducted to impute missing child and maternal covariates specifying predictive mean matching to predict continuous variables and logistic regression to predict categorical variables in each cohort. The 'mi estimate' command was used to combine estimates from 10 imputed data sets.

3 | RESULTS

3.1 | Cohort characteristics

The seven cohorts included a total of 6423 women and their children at the study baseline. Excluding those lost to follow-up and children with missing data on RWG ($n = 1190$) and covariates ($n = 691$), resulted in a final sample of 4542 children (70.7%) being included in the analysis (Table 1). Cohort characteristics between those retained and excluded from the analysis in each cohort were similar (data not shown).

Maternal and child characteristics of the seven cohorts are shown in Table 2. Mean maternal age ranged from 26.6 to 32.6 years. Four studies reported maternal country of birth with most women (66.9%–90.6%) being native born. Of the six cohorts with information on maternal education, five included a higher proportion of women with tertiary education (55.1%–64.2%). The exception was HB, which included a greater proportion of non-tertiary educated women (73.0%). Most women were married across the five cohorts (75.6%–98.1%). The percentage of maternal smoking during pregnancy was 6.1%–17.6% across five cohorts. Apart from LIMIT that consisted of women with BMI ≥25 kg/m^2, the mean maternal BMI was comparable across six other cohorts (24.4–25.9 kg/m^2). For child factors, all seven cohorts had an equal proportion of boys and girls, and mean birth weights of 3.3–3.6 kg. Three studies reported parity with 41.9%–48.3% of children had no siblings. For any breastfeeding duration, four cohorts (BIS, INFANT, INFANT EXTEND and NOURISH) had more children (63.8%–77.7%) with breastfeeding duration ≥6 months. HB had more children with breastfeeding duration <6 months (60.6%). LIMIT and POI had an even proportion of children in the two breastfeeding duration groups. Five out of six cohorts had more children who started solids before 6 months (59.5%–98.2%). The proportion of preterm babies spans from 0.5% to 11.0% in five cohorts. Percentage RWG from birth to around 1 year of age ranged from 21.6%(POI) to 41.7%(HB).

Pooled estimates of univariable and multivariable analyses between maternal/child factors and infant RWG from birth to around 1 year of age are presented in Table 3. Children of native-born women showed a 30% greater tendency to experience RWG than those of

TABLE 2 Maternal and child characteristics of seven cohorts: analysis of determinants of rapid weight gain during infancy

	BIS (n = 716)	HB (n = 444)	INFANT (N = 483)	INFANT EXTEND (n = 260)	LIMIT (n = 1466)	NOURISH (n = 521)	POI (n = 652)
Intervention allocation							
Control	n/a	49.5%	49.3%	49.2%	49.8%	52.0%	51.2%
Intervention		50.5%	50.7%	50.8%	50.2%	48.0%	48.8%
Maternal factors							
Age	31.8 ± 4.3	26.6 ± 5.3	32.3 ± 4.1	32.6 ± 4.1	30.0 ± 5.3	31.7 ± 4.9	32.0 ± 4.9
Country of birth							
Native born	90.6%	66.9%	78.9%	78.5%	n/a	n/a	n/a
Overseas born	9.4%	33.1%	21.1%	21.5%			
Education							
Non-tertiary	44.3%	73.0%	44.9%	35.8%	n/a	35.9%	36.3%
Tertiary	55.7%	27.0%	55.1%	64.2%		64.1%	63.7%
Marital status							
Married	75.6%	90.3%	98.1%	96.9%	n/a	n/a	96.2%
Not married	24.4%	9.7%	1.9%	3.1%			3.8%
Smoking during pregnancy							
Yes	12.4%	17.6%	n/a	n/a	9.1%	6.1%	7.6%
No	87.6%	82.4%			90.9%	93.9%	92.4%
Maternal pre-pregnancy BMI	25.3 ± 5.3	25.1 ± 5.7	24.4 ± 5.1	24.6 ± 5.1	32.4 ± 5.9	25.9 ± 5.1	25.1 ± 4.9
Normal weight	58.1%	59.9%	64.6%	63.1%		51.8%	58.4%
Overweight	25.1%	25.0%	22.8%	24.6%	43.0%	30.7%	28.4%
Obesity	16.8%	15.1%	12.6%	12.3%	57.0%	17.5%	13.2%
Child factors							
Child sex							
Boys	47.6%	51.8%	52.4%	53.1%	49.3%	49.5%	51.4%
Girls	52.4%	48.2%	47.6%	46.9%	50.7%	50.5%	48.6%
Birth weight (kg)	3.5 ± 0.5	3.4 ± 0.6	3.4 ± 0.6	3.3 ± 0.6	3.5 ± 0.6	3.5 ± 0.4	3.6 ± 0.5
<2.5 kg	2.4%	5.9%	6.8%	6.9%	3.7%	0%	1.2%
2.5–4 kg	80.2%	83.8%	80.8%	83.1%	79.1%	88.3%	82.5%
≥4 kg	17.4%	10.4%	12.4%	10.0%	17.2%	11.7%	16.3%

(Continues)

TABLE 2 (Continued)

	BIS (n = 716)	HB (n = 444)	INFANT (N = 483)	INFANT EXTEND (n = 260)	LIMIT (n = 1466)	NOURISH (n = 521)	POI (n = 652)
Parity							
No sibling	43.6%	n/a	n/a	n/a	41.9%	n/a	48.3%
≥1 sibling	56.4%				58.1%		51.7%
Breastfeeding duration							
<6 months	36.2%	60.6%	35.4%	22.3%	47.7%	33.8%	47.9%
≥6 months	63.8%	39.4%	64.6%	77.7%	52.3%	66.2%	52.1%
Solid introduction							
<6 months	98.2%	50.2%	71.2%	92.7%	n/a	59.5%	72.0%
≥6 months	1.8%	49.8%	28.8%	7.3%		40.5%	28.0%
Gestational age (weeks)	39.5 ± 1.4		38.9 ± 2.3	38.9 ± 2.0	39.3 ± 1.7		40.0 ± 1.2
Premature (<37 weeks)	3.5%	n/a	11.0%	7.8%	5.9%	n/a	0.5%
Full term (≥37 weeks)	96.5%		89.0%	92.3%	94.1%		99.5%
Rapid infant weight gain							
Yes	26.1%	41.7%	29.0%	30.4%	23.6%	29.6%	21.6%
No	73.9%	58.3%	71.0%	69.6%	76.4%	70.4%	78.4%

Note: Values are presented as Mean ± SD or percentage (%).
Abbreviations: BIS, Barwon Infant Study; HB, healthy beginnings; INFANT Extend, Infant Feeding Activity and Nutrition Trial Extend; INFANT, Infant Feeding Activity and Nutrition Trial; POI, prevention of obesity in infancy trial.

TABLE 3 Pooled estimates of the association between maternal and child factors and rapid weight gain during infancy from seven cohorts (Barwon Infant Study, Healthy Beginnings, INFANT, INFANT Extend, LIMIT, NOURISH, POI)[a]

	Univariable			Multivariable		
	Odds Ratio	95% CI	p-value	Odds Ratio	95% CI	p-value
Intervention allocation (Intervention vs. control)	0.99	0.73, 1.22	0.66	0.93	0.70, 1.22	0.58
Maternal factors						
Age (years)	1.00	0.99, 1.01	0.78	1.00	0.99, 1.02	0.68
Country of birth (Native born vs. overseas born)	1.30	1.00, 1.68	0.05	1.37	0.99, 1.90	0.06
Education (non-tertiary vs. tertiary)	1.07	0.91, 1.26	0.41	0.89	0.72, 1.10	0.27
Marital status (Married vs. not married)	0.93	0.69, 1.25	0.62	1.16	0.80, 1.69	0.43
Smoking status (Yes vs. no)	1.60	1.28, 2.01	<0.001	1.13	0.86, 1.48	0.37
Maternal pre-pregnancy BMI (kg/m^2)	1.00	0.99, 1.01	0.88	1.01	0.99, 1.04	0.34
Child factors						
Child sex (Boys vs. girls)	1.13	0.99, 1.29	0.07	1.42	1.22, 1.66	<0.001
Birth weight(kg)	0.11	0.05, 0.21	<0.001	0.09	0.04, 0.20	<0.001
Breastfeeding duration (≥6 mo vs. <6 mo)	0.48	0.42, 0.55	<0.001	0.45	0.38, 0.53	<0.001
Solid introduction (≥6 mo vs. <6 mo)	0.77	0.63, 0.93	0.001	0.88	0.71, 1.08	0.22
Parity (≥1 sibling vs. no sibling)	0.68	0.57, 0.81	<0.001	0.88	0.70, 1.11	0.28
Gestational age (weeks)	0.69	0.49, 0.96	0.03	0.69	0.48, 0.98	0.04

Note: Multivariable model included all maternal and child factors in the same model, birth weight and gestational age was analyzed in separate models.
[a]Univariable model included each factor as the exposure and infant RWG as the outcome.
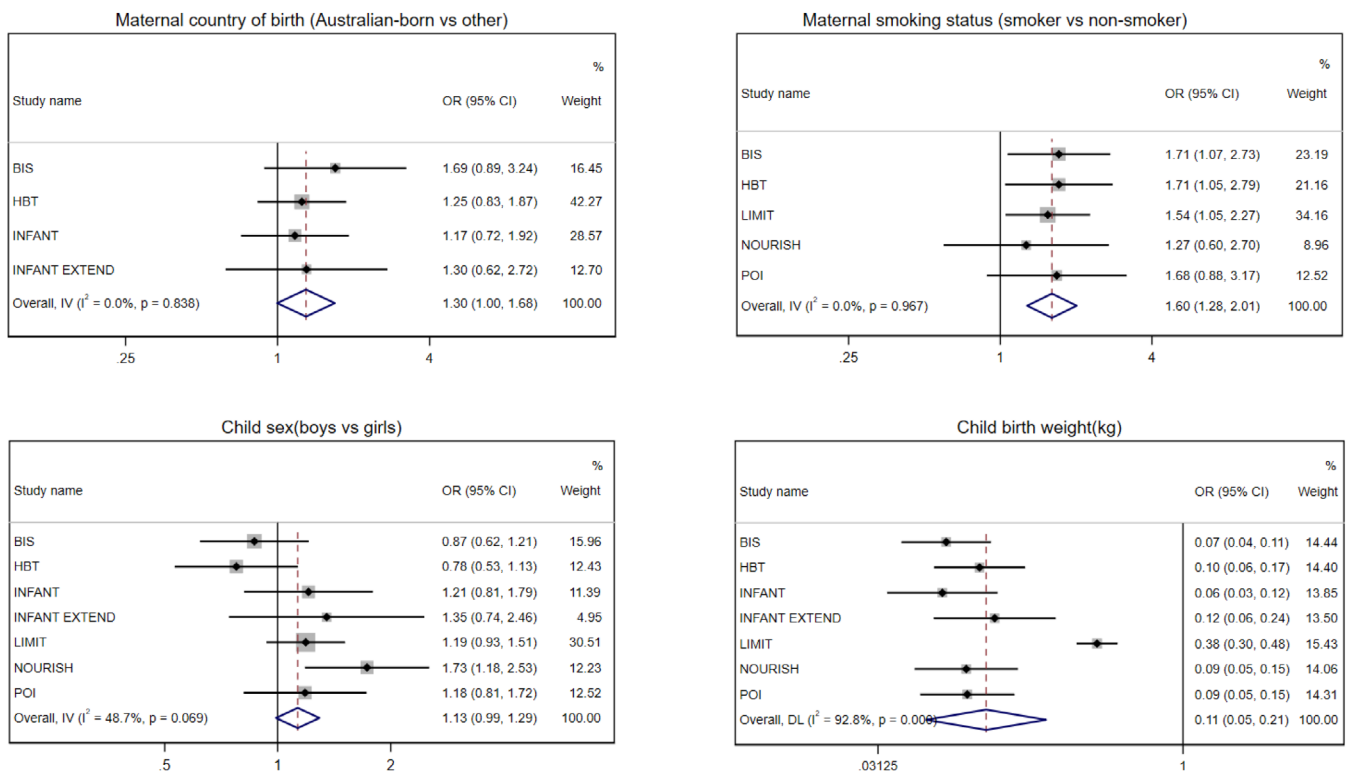

FIGURE 1 Cohort-specific and pooled odds ratio (95% confidence interval) of association between maternal and child factors (maternal country of birth, smoking status, child sex and birth weight) and risk of rapid weight gain during infancy. Estimates were obtained from the univariable model without adjustment for covariate. The overall pooled odds ratio was obtained from either fixed or random-effects meta-analysis
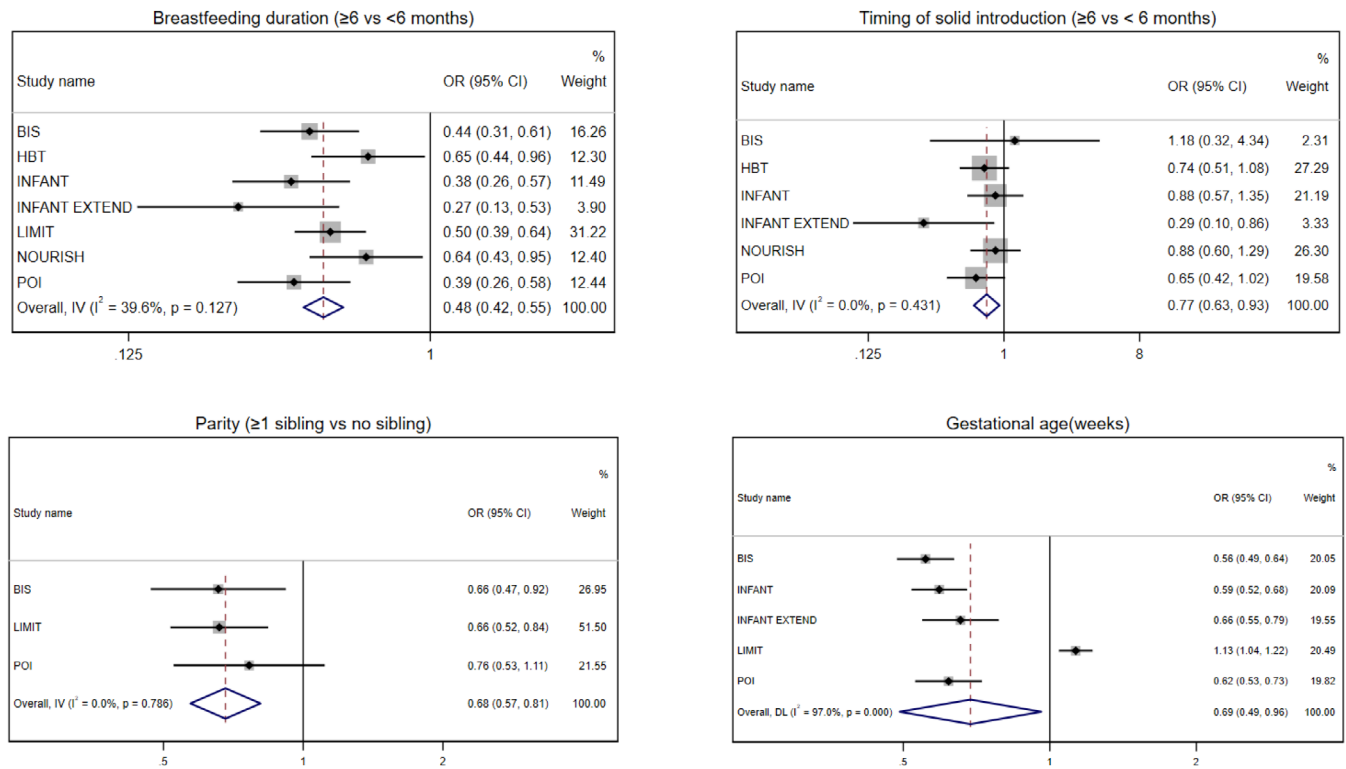
FIGURE 2 Cohort-specific and pooled odds ratio (95% confidence interval) of association between child factors (breastfeeding duration, timing of solid introduction, parity and gestational age) and risk of rapid weight gain during infancy. Estimates were obtained from the univariable model without adjustment for covariate. The overall pooled odds ratio was obtained from either fixed or random-effects meta-analysis

overseas-born women ($p = 0.05$). Maternal smoking was associated with a 60% higher RWG risk ($p < 0.001$). Furthermore, boys appeared to show a 13% higher risk of experiencing RWG than girls ($p = 0.07$). In contrast, higher child birth weight, any breastfeeding duration≥6 months, solid introduction ≥6 months, gestational age and children with siblings were associated with lower RWG risk (OR ranged from 0.11 to 0.77, $p < 0.05$). The cohort-specific univariable associations of these factors and infant RWG are shown in Figures 1 and 2. The significant associations for maternal smoking, parity and timing of solid introduction attenuated in the multivariable model (Table 3). The attenuation of the associations was largely attributable to adjustment for child birth weight. Associations of child sex, birth weight, any breastfeeding duration and gestational age with infant RWG were significant in the multivariable model ($p < 0.05$). Cohort-specific results from the multivariable model are presented in Figures S1 and S2. No evidence of an association was found for maternal age, education level, marital status, BMI or intervention allocation in all models (Table 3, Figures S3 and S4).

3.2 | Additional analysis

Mediation analyses were undertaken to test the potential mediating effects of child birth weight on the associations between maternal smoking, parity, timing of solid introduction and RWG. Cohort-specific and pooled indirect effects are shown in Figure S5. Child birth weight mediated the association between maternal smoking and RWG with a pooled

indirect effect of 1.46 95% CI 1.21, 1.76. Significant mediating effects of child birth weight on the association between parity (≥1 sibling) and RWG were also revealed (0.71, 95% CI 0.55, 0.93). Child birth weight was found to mediate the association between timing of solid introduction and RWG in two cohorts (INFANT and INFANT EXTEND), but the overall pooled indirect effect was not statistically significant (0.87, 95% CI 0.69, 1.10).

The associations between the categorical form of maternal BMI, birth weight and gestational age with infant RWG are shown in Table S2. Birth weight ≥4 kg (OR 0.17, 95% CI 0.12, 0.23) and full term ≥37 weeks (OR 0.20, 95% CI 0.04, 1.05) were associated with lower odds of infant RWG. RWG risk did not differ by maternal BMI categories. Additional analyses excluding three cohorts showed similar results (Tables S3 and S4).

A total of 5223 (81.5%) participants were included in the analyses with the imputation of missing child and maternal covariates. A comparison of results from multivariable analyses without and with multiple imputations is shown in Table S5 and revealed similar results with comparable effect sizes for all variables except for the maternal country of birth where the associations observed were somewhat attenuated (OR 1.19 95% CI 0.88, 2.37).

4 | DISCUSSION

Using data from seven cohorts comprising over 4000 participants, this study assessed the maternal and child determinants of RWG in the

1st year of life. Evidence of significant associations was found for maternal smoking status, child sex, birth weight, gestational age, parity, any breastfeeding duration and timing of solid introduction with infant RWG. The significant association of maternal smoking status, timing of solid introduction and parity with infant RWG attenuated after adjusting for child birth weight. Maternal country of birth also appeared to be a potential determinant of infant RWG. In contrast, maternal age, education level, marital status and pre-pregnancy BMI were not associated with infant RWG.

Our study findings corroborate results from the limited evidence base on determinants of infant RWG. Congruent with our findings, studies in German [23] and Swedish children[24] revealed that maternal smoking during pregnancy increased the risk for RWG from birth to 24 months and from birth to 3–4 or 6 months, and the evidence of association attenuated after adjustment for other factors including birth weight. Our results suggest that the increased RWG risk in children of smoking women was mediated by child birth weight. It has been suggested that in utero exposure to carbon monoxide and nicotine reduces foetal oxygen supply, resulting in intrauterine growth restriction and low birth weight, which in turn promotes RWG during infancy.[25,26] Similar to our findings on the maternal country of birth, previous studies reported ethnic differences in RWG from birth to 6 months[27] and growth patterns during infancy.[28,29] Ethnic differences in infant growth are likely influenced by sociocultural factors and ethnic variations in infant feeding practices.[30]

In agreement with findings from studies of German,[27] Swedish[24] and Canadian children,[31] our study found that neither maternal education nor pre-pregnancy BMI was predictive of infant RWG. Maternal education and BMI might not directly influence RWG but may be more likely to affect factors associated with RWG. For instance, as a proxy for socioeconomic position, maternal education is likely to influence maternal lifestyle habits (e.g. smoking) and infant feeding, which may, in turn, influence infant RWG. Indeed, Reeske et al.[27] found a higher RWG prevalence in a low versus high maternal education group, but the difference disappeared after adjusting for maternal smoking and infant feeding. Furthermore, our study included cohorts that had a higher proportion of tertiary-educated women, which may also contribute to a lack of association for maternal education. Higher maternal BMI as a risk factor for obesity in children is widely recognized and may be attributable to genetics and metabolic pathways as well as maternal influences on child lifestyle habits.[32] The lack of association between maternal BMI and infant RWG revealed in our study suggests that infant RWG is unlikely to be an underlying factor contributing to the link between maternal BMI and childhood obesity. However, given the paucity of literature on maternal BMI and infant RWG, further investigation is warranted.

Our finding that boys showed a higher RWG risk than girls is consistent with the existing studies. In a Swedish cohort (n = 1780), girls were 53% and 29% less likely to experience RWG from birth to 3–4 and 6 months, respectively, than boys.[24] Similarly, a German study (n = 370) also found that boys tend to show a greater risk of RWG from birth to 24 months than girls.[23] Sex differences in infant growth patterns have been widely documented. A large Dutch study observed sex differences in both foetal and infant growth with boys exhibiting higher body weight than girls from birth to 12 months.[33] The differences in male and female placental function and biomarkers may explain the sex-specific growth patterns during infancy.[34] For example, male and female placentae have different protein and gene expressions. In addition, female foetuses seem to have a higher level of certain placental biomarkers than males during the first trimester of pregnancies, resulting in both sex-specific foetal and infant growth.[34]

Associations of similar strengths between higher birth weight and gestational age with lower RWG risk have been shown in other studies.[24,27] Rapid growth is commonly observed in low birth weight or preterm infants,[4] thought to be partly due to a recovery from undernutrition in utero. Similar mechanisms apply to gestational age. It is worth noting that WHO growth standards describe normal child growth under optimal environmental conditions and do not account for gestational age. The use of WHO growth standards may inappropriately characterize growth for preterm infants. However, the influence on the current findings is expected to be small as the proportion of preterm infants in our sample is low.

Several studies explored parity as a risk factor for infant RWG. Consistent with our findings, two studies found that children with siblings had a lower risk of RWG than first-born children.[23,35] It is postulated that women with first pregnancy are more likely to have children with low birth weight than women with multiple pregnancies because uterine efficiency for delivering oxygen and nutrients to the foetus tends to increase with more pregnancies.[36] Another explanation is that women in the first pregnancy are more likely to experience breastfeeding problems (e.g. early unintended breastfeeding cessation and formula supplementation), consequently increasing RWG risk.[37,38] Indeed, the current study found that the association between parity and RWG risk was mediated by child birth weight.

The beneficial effects of breastfeeding in lowering RWG risk during infancy are well-documented[24,27,39,40] and are supported by several possible hypotheses. Breastfeeding women may be more likely to practice responsive feeding (i.e. identifying and responding appropriately to infants' hunger and satiety cues),[41] which prevents overfeeding. Specific nutritional components of breast milk (e.g. leptin and ghrelin) may support appetite control and regulation and in turn favourable energy balance and growth patterns.[42] Additionally, breast milk has a lower protein content than infant formula. It has been proposed that excess protein intake may convert to glucose via gluconeogenesis, which could be subsequently stored as fat and contribute to excess body weight and fat gain.[43]

The existing literature on the timing of solid introduction focused on its relationship with obesity risk. One study found no evidence of an association between timing of solid introduction and change in weight z-score from birth to 12 months.[44] A link between early introduction of solids before 4 months and greater obesity risk has been revealed in some studies,[45] likely attributable to a higher intake of energy and protein from the early introduction of solids.[45] Our finding that introduction of solids after 6 months predicted lower infant RWG risk supports these findings. Other factors may confound the association as the significant associations disappeared after controlling for other child and maternal factors.

The current study has several strengths and limitations that warrant discussion. This is the first study that comprehensively assessed the associations of a broad range of maternal and child factors with infant RWG in several cohorts of Australian and New Zealand children. Moreover, mediation analyses were conducted to explore potential meditational pathways. The large sample size and overall synthesis of results across seven cohorts encompassing diverse population groups enhance both the robustness and generalizability of the study findings. It is important to note that the average attrition rate across seven studies is about 30%. However, the comparison of cohort characteristics between those retained and excluded from the current analysis was similar. Analyses with multiple imputations of missing covariates revealed similar results. Although we explored a broad range of factors associated with RWG during infancy, other factors such as maternal alcohol consumption[35] and gestational weight gain,[24,27,31] which have been previously shown to be risk factors of infant RWG, were not assessed in our study.

This study contributes to the limited body of evidence on the determinants of infant RWG and provides valuable insights on at-risk groups and preventive strategies for early health promotion programs and interventions. Public health policy and practice could focus on prenatal intervention strategies to help women (particularly those in their first pregnancy) to deliver full-term children with healthy birth weight such as supporting women to abstain from smoking during pregnancy. Moreover, promote extended breastfeeding and discourage the early introduction of solids during the postnatal period.

5 | CONCLUSION

Several maternal and child factors including maternal country of birth, smoking during pregnancy, child sex, birth weight, gestational age, parity and early infant feeding were identified as determinants of RWG in the 1st year of life. The findings will inform the identification of at-risk groups and the design of targeted strategies for early health promotion and chronic disease prevention programs.

AUTHOR CONTRIBUTIONS

MZ and KJC conceived the study. MZ conducted the statistical analysis, interpreted the results and drafted the manuscript. KJC, KDH, PV, JD, LMW, LB, RT, RB, SM, PDS and MLKT collected data and contributed to results interpretation. All authors critically reviewed and approved the final manuscript.

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CONFLICT OF INTEREST

The authors declared no conflict of interest.

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