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Regional variation in weight-for-height *z*-scores and surface area/body mass ratio of Chilean children from birth to 3 years of age

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Abstract

Objective: The objectives of the study were to see how much of the variation in weight-for-height *z*-scores (WHZ) and surface area/body mass ratio (SA/mass) were associated with regional (county) differences including mean temperature.

Subjects and methods: Longitudinal data were obtained from routine medical check-ups on 8,373 children from nine counties across Chile. WHZ and SA/mass were calculated from weight and height from birth to 3-years old at 6 monthly intervals. County of birth was used as an independent variable after controlling for sociodemographic factors. Sequential repeated-measures ANOVAs were used to analyze the changes in WHZ and SA/mass over the seven measurements from birth to 3 years of age. Simple and partial Pearson correlations were calculated between WHZ and annual mean temperature and between SA/mass and annual mean temperature after controlling for socioeconomic factors.

Results: County of birth was significantly ($p < 0.001$) associated with both WHZ and SA/mass. There was a progressive decrease in WHZ means and a progressive increase in SA/mass means from colder to warmer counties. Significant negative correlation in WHZ ($r < -0.864$) and significant positive correlations in SA/mass ($r > 0.821$) were found with the annual mean temperature from 18 months of age onwards and in the overall mean age.

Conclusion: This study suggests that WHZ and SA/mass variation may be influenced by ecogeographical factors in this Chilean sample.

KEYWORDS
infancy, childhood, regional variation, nutritional status, Chile

1 | INTRODUCTION

Childhood nutritional status is nowadays characterized by overnutrition and consequently high prevalences of overweight and obesity have been found in developed countries and many developing countries. While several studies have focused on environmental, socioeconomic, and biological factors affecting the weight of children, few studies have examined the regional variation in nutritional status (El Mouzan et al., 2009; Willms, Tremblay, & Katzmarzyk, 2003). In these two studies, the authors found that significant regional effects could not be entirely explained by adjusting for other variables. According to Dutton and McLaren (2011), region-specific variables may be considered as 'ecological' variables to which individuals in a region are exposed. Some of these variables may be economic (e.g., childcare policy and food prices), socio-cultural (e.g., attitudes toward physical activity), or physical (e.g., the built environment and access to healthy food vendors). Different factors contribute to potential regional variation in nutritional status, such as dietary variation, levels of physical activity, and socioeconomic differentiation (Vanasse, Demers, Hemiari, & Courteau, 2006). Furthermore, education, income, and regional budget distribution may have heterogeneous effects across regions due to the interaction with individual characteristics, therefore producing different outcomes (Dutton & McLaren, 2011; El Mouzan et al., 2009). Thus, it is important to know whether inter-regional variability in nutritional status is reflected in other socio-demographic variables. For example, it is possible that some regions may associate with catch-up growth as a product of food deprivation during early growth, consequently suggesting a "famine" developmental pathway (Benyshek, 2007). In contrast, other regions could have excessive calorie intake, suggesting a "feast" developmental pathway.

Childhood nutritional status in Chile is characterized by overnutrition and high prevalences of overweight and obesity (Corvalán et al., 2017). In less than 30 years, Chile has experienced important changes leading to an epidemiological and nutritional transition (Kain, Uauy, Lera, Taibo, & Albala, 2005). The infant mortality rate has fallen from 19.5‰ in 1985 to 7.0‰ in 2015 (Central Intelligence Agency, 2016) and it is the second lowest in Latin America. The prevalence of stunted children at 6 years of age has fallen from 4.90% in boys and 5.40% in girls in 1987 to 2.70 and 2.50%, respectively, in 2003. Furthermore, underweight has fallen from 4.20% in boys and 3.90% in girls to 1.80 and 1.70%, respectively over the same time period (Junaeb, 2015; Kain et al., 2005) suggesting that stunting and underweight are no longer a significant public health issue in Chile (Uauy & Castillo, 2001).

In contrast, obesity is a matter of concern in Chile. Nowadays, four million Chileans show signs of obesity at all age stages and the condition constitutes the second cause of years of potential life lost by death or premature disability and ranks the sixth most common cause of death (Atalah, 2012). Additionally, childhood obesity has tripled over the last decades and it is still rising (Kain, Martinez, Close, Uauy, & Corvalan, 2016). For instance, the prevalence of obesity in children at 6-years old has increased from 5.5% in boys and 4.8% in 1987 up to 26.0% in boys and 21.2% in girls in 2013 (Junaeb, 2015). This increase in childhood obesity during the last decades has affected the health and well-being of this population.

The causes of these critical changes have been associated with demographic, social and economic factors, leading to an epidemiological and nutritional transition (Kain et al., 2005). First, substantial improvements such as sanitary conditions and control of infectious diseases ameliorated the health conditions and child growth of low and middle socio-economic status (Albala, Vio, Kain, & Uauy, 2002; Kain, Uauy, Vio, & Albala, 2002; Kain et al., 2005; Uauy, Albala, & Kain, 2001). Second, shrinking of the family structure, higher life expectancy at birth, population ageing, and decline of birth and fecundity rates, have affected the Chilean demographic profile (Atalah, 2012). Third, improvements in the income per capita in poor families and changes of sedentary and dietary habits (high caloric intake and low fiber diet) have been determinants of Chilean nutritional status change (Atalah, 2012). And fourthly, unhealthy food marketing addressing children has strongly effected on the rise of childhood obesity (Uauy, Caleyachetty, & Swiburn, 2010). All these factors resulted in a rapid nutritional transition since the mid-1980s (Kain et al., 2005), which led to a postnutritional transition stage (Vio, Albala, & Kain, 2008) thereafter.

However, child obesity figures show regional variation. For instance, the National Council for Students Assistance and Scholarships (Junta Nacional de Auxilio Escolar y Becas, JUNAEB) publishes each year the prevalence of wasting, stunting, and obesity of preschool and schoolchildren by regions (www.junaeb.cl/mapa-nutricional). Results obtained in 2015 showed that the lowest prevalence of obesity in children aged between 4 and 5 years old was found in Antofagasta (Northern Chile, 20.8%) and the highest prevalence was found in Magallanes (26.4%), the southernmost Chilean region. Previous reports from the JUNAEB and other studies also show an increase in the prevalence of obesity from north to south (Atalah, Urteaga, Rebolledo, Delfín, & Ramos, 1999; Loaiza & Atalah, 2006; Loaiza & Bustos, 2007).

Chilean regional variation in nutritional status may be associated with different ecogeographical, climatic, social, cultural and/or historical factors. The Chilean population is highly diverse in terms of culture and ethnicity. Chilean people have a genetic and cultural mixture of native South American and other traditions (European and African populations) (http://www.chilegenomico.cl/datos-genomicos/). Moreover, historical and recent migration from neighbor countries, local traditions, adapted economies to different environments and modern economies make Chile a complex cultural mosaic. Easter Island is one of these groups being part of this Chilean diversity. Easter Island people have Polynesian traditions mixed with European and Chilean traditions as consequence of mixture with local people (Cruz-Coke, 1988; Gonzalez-Perez et al., 2006; Hurles et al., 2003). Moreover, mainland Chileans have migrated to Easter Island without mixing with local population and conserving their Chilean traditions. Nowadays, as part of the Chilean administration, people living in Easter Island receive medical care from the public health system. However, there is a dearth of information on growth of Easter Island people that can be compared with the rest of Chilean population for health purposes. Similarly, there is a dearth of information on growth of Chilean children from different regions and counties, with the exception of Santiago (Kain, Corvalan, Lera, Galvan, & Uauy, 2009; Kain et al., 2016), and therefore they may not represent the whole variation within the country.

Additionally, because of its north to south orientation, Chile has a wide temperature range, which may influence the nutritional status of children. Some authors argue that these differences may be due to regionally related unhealthy diets and maternal overweight derived from cultural and behavioral factors (Durán, Labraña, & Sáez, 2015; Loaiza & Atalah, 2006). On the other hand, it has been observed that extinct and modern adult humans conform to Bergmann's rule (Béguelin, 2010; Bergmann, 1847; Foster & Collard, 2013; Fukase et al., 2012; Gilligan & Bulbeck, 2007; Katzmarzyk & Leonard, 1998a; Kurki, Ginter, Stock, & Pfeiffer, 2008; Newman & Munro, 1955; Roberts, 1953; Wells, 2012) with a negative correlation between environmental mean temperature and body mass within populations.

In Chile there are no previous longitudinal studies that test whether there are differences in weight-for-height or surface area means of children living in different counties and whether there is a correlation between annual mean temperature of each county and the weight-for-height or surface area means at different age intervals. Therefore, this study has two aims: (1) to examine the regional variation in weight-for-height and surface area/body mass ratio controlling for sociodemographic variables and considering diverse counties and cultural backgrounds within Chile and (2) to analyze the correlation between weigh-for-height and the annual mean temperature and the correlation between surface area/body mass ratio and the annual mean

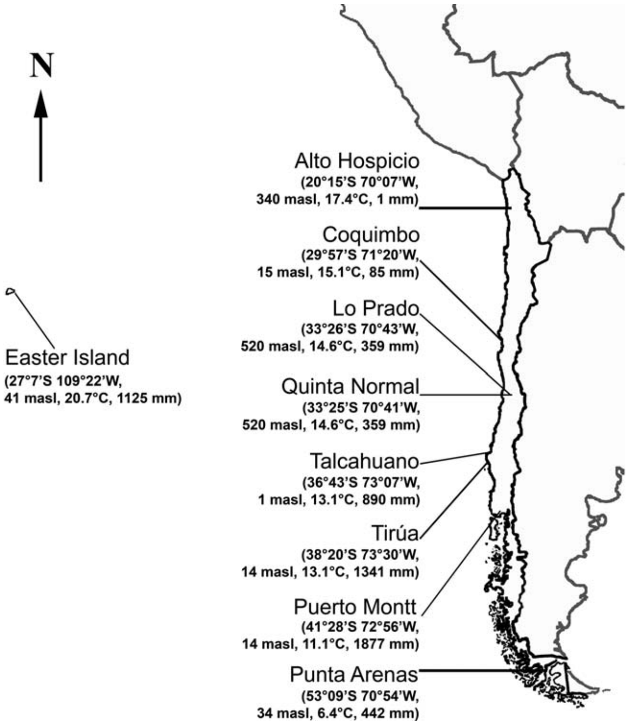

FIGURE 1 Map of Chile showing the counties studied and their latitudes, meters above the sea level (masl), annual mean temperatures, and precipitation

temperature after controlling for sociodemographic variables of each county in Chilean children between birth and 3 years of age.

2 | SUBJECTS AND METHODS

This was a retrospective longitudinal study aimed at evaluating the associations of weight-for-height (WHZ) in relation to regional variation of Chilean infants born between January 2007 and January 2011 from eight urban counties (Easter Island, Alto Hospicio, Coquimbo, Lo Prado, Quinta Normal, Talcahuano, Tirúa, Puerto Montt, and Punta Arenas) (Fig. 1). Data obtained from routine medical check-ups were utilized to study children between birth and 3-years old. These routine check-ups were carried out by trained physicians and nurses according to international procedures (Cameron, 2004; Leyton, Becerra, Castillo, Heather, & Santander, 2013) in all health centers across Chile starting a few days after birth and continuing up to 9 years of age. Inclusion-exclusion criteria were: (1) a date of birth between January 2007 and January 2011, (2) born and raised until 3 years of age in the same region, (3) more than 7 measurements obtained about every 3 months until 3 years of age (including weight and height at birth), (4) more than 36 weeks of gestational age, and (5) not been diagnosed with any developmental or genetic disorders.

As children were not measured at exactly 6 monthly intervals, third order polynomial regressions were used to generate the best height and weight fitting curves (Brush, Harrison, Baber, & Zumrawi, 1992; Gergonne, 1974; Karim & Mascie-Taylor, 2001; Stigler, 1974; Sun & Jensen, 1993). From the total number of children (24,275 cases), 15,902 children were excluded mainly due to insufficient measurements to be able to fit the third order polynomials (10,950 cases, 68.86%), inaccurate height and weight estimations through curve fitting (4,280 cases, 16.21%), missing *z* scores values or outside the WHO 2006 standard (WHO, 2006) outlier ranges (282 cases, 1.77%), database mismatch (277 cases, 1.74%), preterm infants, developmental, and genetic disorders (65 cases, 0.41%), and nonindigenous Easter Island children (48 cases, 0.30%). The final sample size was 8,373 individuals of whom 4,080 were females and 4,293 males. Differences in WHZ at all age intervals were significant between the analyzed and nonanalyzed children, whereas Cohen's *D* statistics indicated negligible effect sizes.

Weight and height were used to calculate WHZ utilizing the WHO Anthro program (http://www.who.int/childgrowth/software/en/), while surface area (SA) was calculated from weight and height using the equation of Gehan and George (1970), which has been used in previous studies (Katzmarzyk & Leonard, 1998b; Wells, 2000). SA/mass was calculated as SA(cm^2)/mass(kg). Both, WHZ and SA/mass were the dependent variables. The independent variable was the county of birth. The following covariates were controlled: (1) Household occupation: divided into four groups: non-waged occupations, unskilled manual occupations, skilled manual occupations, and managerial, technical, and professional occupations. (2) Birth order: divided into 1st, 2nd, 3rd, and 4th+ born. (3) Sex: male or female. (4) Year of birth: 2007, 2008, 2009, and 2010 (January 2011 was included within 2010). (5) Age of the mother: divided into four age groups of 10 to 19, 20–29, 30–39, and 40–49 years of age. (6) Age of cessation of receiving breast milk. (7) Age of commencement of formula-based milk. (8) Age of commencement of giving other types of food. The last three covariates were divided into three groups: before 3 months of age, between 3 and 6 months of age, and after 6 months of age.

To analyze the changes in WHZ and SA/mass over the 7 measurements, sequential (Type I) repeated-measures ANOVA were used. The effect size of each independent variable was computed using eta square (η^2) statistic. A small effect size was defined as $\eta^2 \sim 0.01$, medium effect size if $\eta^2 \sim 0.06$, and large effect size if $\eta^2 \sim 0.14$ following Cohen (1988). Simple correlations between (1) WHZ and annual mean temperature of each county, (2) WHZ and average taxable monthly income of each county, (3) WHZ and the percentage of poverty of each county, (4) SA/mass and annual mean temperature of each county, (5) SA/mass and the average taxable monthly income of each county, and (6) SA/mass and the percentage of poverty of each county, were computed at each age interval. Partial correlations between WHZ and annual mean temperature as well as SA/mass and annual mean temperature controlled by the average taxable monthly income and the percentage of poverty were computed to test whether the association between temperature and body mass, as well as temperature and body surface remained significant. Simple and partial correlations were performed for all counties as well as after separately removing Tirúa, Easter Island as well as both counties together, in order to test whether these two counties exerted a strong effect on the correlation results, due to their high ethnic component and different socioeconomic conditions. Annual mean temperature data for each county was obtained

TABLE 1 Sequential repeated-measurements ANOVA and Bonferroni post-hoc comparisons in relation to changes of WHZ after entering variable county of birth (*Significant at $p < 0.05$, **Significant at $p < 0.01$, ns: nonsignificant)

		Interaction			Within-subjects			Between-groups		
Variable	Overall Mean	*F*	*p* value	η^2	*F*	*p* value	η^2	*F*	*p* value	η^2
Easter Island	0.638	822.324	<0.001	0.09	15.691	<0.001	0.015	16.026	<0.001	0.015
Alto Hospicio	0.644									
Coquimbo	0.697									
Lo Prado	0.700									
Quinta Normal	0.614									
Talcahuano	0.771									
Tirúa	0.971									
Puerto Montt	0.865									
Punta Arenas	0.856									

	Bonferroni post-hoc comparison between counties							
	Easter Island	Alto Hospicio	Coquimbo	Lo Prado	Quinta Normal	Talcahuano	Tirúa	Puerto Montt
Easter Island								
Alto Hospicio	ns							
Coquimbo	ns	ns						
Lo Prado	ns	ns	ns					
Quinta Normal	ns	ns	ns	ns				
Talcahuano	ns	ns	ns	ns	**			
Tirúa	**	**	**	**	**	**		
Puerto Montt	**	**	**	**	**	ns	ns	
Punta Arenas	*	**	**	**	**	ns	ns	ns

from climate-data.org, while the average taxable monthly income and the percentage of poverty of each county were obtained from county reports (Biblioteca del Congreso Nacional de Chile, 2015). Significance level was established at 0.05.

2.1 | Ethical clearance

Study protocols were approved by ethical committees from the Iquique Health Service, Coquimbo Health Service, South Eastern Santiago Health Service, Western Santiago Health Service, Talcahuano Health Service, Arauca Health Service, and Valdivia Health Service as well as Alto Hospicio, Coquimbo, Quinta Normal, Talcahuano, Tirúa, Puerto Montt, and Punta Arenas Municipality Health Directors, as well as the Director of Hanga Roa Hospital.

3 | RESULTS

The results of the sequential repeated-measures ANOVA in relation to changes in WHZ and SA/mass from birth to 3 years of age by county are presented in Tables 1 and 2, and Figures 2 and 3. In Figures 2 and 3 Easter Island, Alto Hospicio, and Coquimbo were colored light grey, Santiago counties (Lo Prado and Quinta Normal) and Talcahuano in medium grey, and Tirúa, Puerto Montt, and Punta Arenas in black. Small dashed lines indicate that the county has higher annual mean temperature than the large dashed lines, while large dashed lines indicate that the county has higher annual mean temperature than the continuous lines. As can be seen from Figure 2, the general pattern of change in mean WHZ among counties showed an increase from birth to 18 months and a slight decline thereafter. However, the significant interaction effect ($p < 0.001$) indicated that the county lines were not parallel which was mainly accounted for by the sharper rise between birth and 6 months of age in Tirúa and the flatter profile of Easter Island and Alto Hospicio. When the average *z* score over the seven measurements was calculated for each county there was significant heterogeneity in means ($p < 0.001$) with the highest mean in Tirúa (0.971 SD), followed by Puerto Montt (0.865 SD) and Punta Arenas (0.856 SD), while Quinta Normal had the lowest means (0.614 SD) followed by Easter Island (0.638 SD), and Alto Hospicio (0.644 SD). While WHZ at birth did not show clear separation between northern and southern counties, clearer differentiation was visible from 12 months onwards. Post-hoc tests (Table 1) showed that the main differences were due to (a) the lower overall mean in Easter Island compared with Tirúa, Puerto Montt, and Punta Arenas (b) the lower overall mean in Alto Hospicio compared with Tirúa, Puerto Montt, and Punta Arenas (c) the lower overall mean in Coquimbo compared with Tirúa, Puerto Montt, and Punta Arenas (d) the lower overall mean in Lo Prado

TABLE 2 Sequential repeated-measurements ANOVA and Bonferroni post-hoc comparisons in relation to changes of SA/mass showing results after entering variable county of birth (*Significant at $p < 0.05$, **Significant at $p < 0.01$, ns: nonsignificant)

	Overall	Interaction			Within-subjects			Between-groups		
Variable	Mean	*F*	*p* value	η^2	*F*	*p* value	η^2	*F*	*p* value	η^2
Easter Island	4.922	25.28	<0.001	0.02	12.271	<0.001	0.012	12.093	<0.001	0.012
Alto Hospicio	4.942									
Coquimbo	4.944									
Lo Prado	4.936									
Quinta Normal	4.950									
Talcahuano	4.916									
Tirúa	4.873									
Puerto Montt	4.909									
Punta Arenas	4.892									

	Bonferroni post-hoc comparison between counties							
	Easter Island	Alto Hospicio	Coquimbo	Lo Prado	Quinta Normal	Talcahuano	Tirúa	Puerto Montt
Easter Island								
Alto Hospicio	ns							
Coquimbo	ns	ns						
Lo Prado	ns	ns	ns					
Quinta Normal	ns	ns	ns	ns				
Talcahuano	ns	ns	ns	ns	*			
Tirúa	*	**	**	**	**	**		
Puerto Montt	ns	**	**	**	**	ns	ns	
Punta Arenas	ns	*	*	*	**	ns	ns	ns

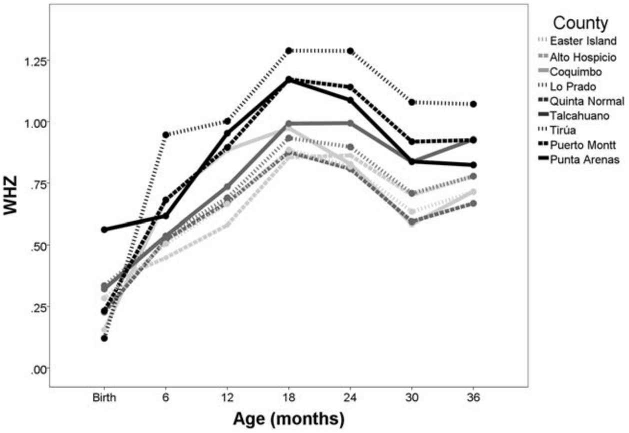

FIGURE 2 WHZ means at 6-month intervals by county of birth. Easter Island, Alto Hospicio, and Coquimbo are colored light grey, Santiago counties (Lo Prado and Quinta Normal) and Talcahuano in medium grey, and Tirúa, Puerto Montt, and Punta Arenas in black. Small dashed lines indicate that the county has higher annual mean temperature than the large dashed lines. Large dashed lines indicate that the county has higher annual mean temperature than the continuous lines

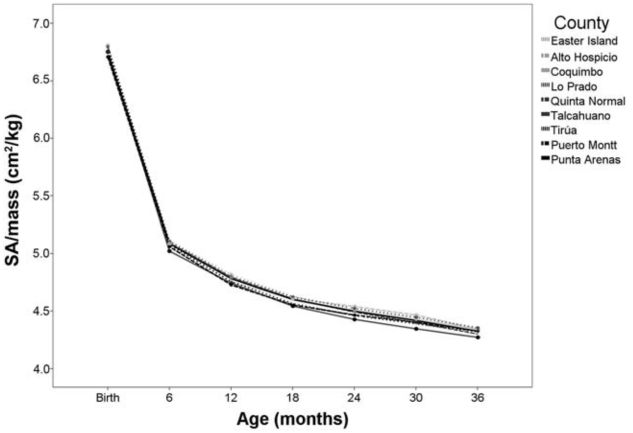

FIGURE 3 SA/mass means at 6-month intervals by county of birth. Easter Island, Alto Hospicio, and Coquimbo are colored light grey, Santiago counties (Lo Prado and Quinta Normal) and Talcahuano in medium grey, and Tirúa, Puerto Montt, and Punta Arenas in black. Small dashed lines indicate that the county has higher annual mean temperature than the large dashed lines. Large dashed lines indicate that the county has higher annual mean temperature than the continuous lines

TABLE 3 Pearson correlation coefficients between WHZ and annual mean temperature, and between SA/mass and annual mean temperature by each age interval (*Significant at $p < 0.05$, **Significant at $p < 0.01$)

		All counties	Removing Tirúa	Removing Easter Island	Removing Tirúa and Easter Island
WHZ	Birth	−0.437	−0.553	−0.557	−0.649
	6 months	−0.378	−0.563	−0.287	−0.513
	12 months	−0.693*	−0.766*	−0.678	−0.789*
	18 months	−0.701*	−0.851*	−0.683	−0.887**
	24 months	−0.631	−0.798*	−0.574	−0.793*
	30 months	−0.534	−0.666	−0.466	−0.641
	36 months	−0.429	−0.522	−0.315	−0.433
	Overall mean	−0.679*	−0.834**	−0.635	−0.842*
SA/mass	Birth	0.219	0.201	0.257	0.262
	6 months	0.403	0.844**	0.274	0.769*
	12 months	0.708*	0.760*	0.720*	0.806*
	18 months	0.672*	0.758*	0.764*	0.913**
	24 months	0.516	0.579	0.661	0.820*
	30 months	0.373	0.406	0.558	0.717
	36 months	0.243	0.245	0.449	0.618
	Overall mean	0.545	0.688	0.629	0.879**

compared with Tirúa, Puerto Montt, and Punta Arenas, (e) the lower overall mean in Quinta Normal compared with Talcahuano, Tirúa, Puerto Montt, and Punta Arenas, and (f) the lower overall mean in Talcahuano compared with Tirúa. These comparisons indicated that northern counties were statistically different to southern counties, whilst Easter Island was significantly different to southern counties. The effect size of the interaction was moderate, while the effect size of within-subjects and between-groups effect were small.

As can be seen from Figure 3, the general pattern of change in mean SA/mass among counties showed a fast decrease from birth to 6 months and a slight decline thereafter. However, the significant interaction effect ($p < 0.001$) indicated that the county lines were not parallel. When the average values over the seven measurements was calculated for each county there was significant heterogeneity in means ($p < 0.001$) with the highest mean in Quinta Normal (4.950), followed by Coquimbo (4.944), and Alto Hospicio (4.942), while Tirúa had the lowest means (4.873) followed by Punta Arenas (4.892), and Puerto Montt (4.909). While SA/mass at birth did not show clear separation between northern and southern counties, clearer heterogeneity was visible from 12 months onwards. The post-hoc tests (Table 2) showed that the main differences were due to (a) the higher overall mean in Easter Island compared with Tirúa (b) the higher overall mean in Alto Hospicio compared with Tirúa, Puerto Montt, and Punta Arenas (c) the higher overall mean in Coquimbo compared with Tirúa, Puerto Montt, and Punta Arenas (d) the higher overall mean in Lo Prado compared with Tirúa, Puerto Montt, and Punta Arenas, (f) the higher overall mean in Quinta Normal compared with Talcahuano, Tirúa, Puerto Montt, and Punta Arenas, and g) the higher overall mean in Talcahuano compared with Tirúa. These comparisons indicated that the SA/mass of northern counties was statistically different to southern counties. Easter Island only showed a significant difference with Tirúa. The effect size of the interaction was moderate, while the effect size of within-subjects and between-groups effect were small.

The correlations between WHZ and annual mean temperature were negative (Table 3). When all counties were analyzed, significant correlations were found at 12 and 18 months of age and for the overall mean. As observed in Figure 4, Tirúa showed the highest WHZ mean after 6 months of age. After removing Tirúa, significant negative correlations were found at 12, 18, 24 months of age, and in the overall mean. After removing Easter Island, there were no significant correlations. When Tirúa and Easter Island were removed, significant negative correlations were found at 12, 18, 24 months of age, and in the overall mean.

Correlations between SA/mass and annual mean temperature were positive. When all counties were analyzed, significant correlations were found at 12 and 18 months of age. As seen in Figure 5, Tirúa showed the lowest SA/mass mean after 6 months of age. After removing Tirúa, significant positive correlations were found at 6, 12, and 18 months of age. After removing Easter Island, significant negative correlations were found at 12 and 18 months of age. When Tirúa and Easter Island were removed, significant negative correlations were found at 6, 12, 18, and 24 months of age, as well as in the overall mean.

Table 4 presents the Pearson correlation coefficients between WHZ and SA/mass with average taxable monthly income and percentage of poverty by each age interval. When all counties were included, significant negative correlations were found at 6, 24, 30, and 36 months of age, as well as for the overall mean. However, the correlation between average taxable monthly income and WHZ may be spurious due to the effect of Tirúa, which has the lowest average taxable monthly income (USD 501), while the second lowest income is Puerto Montt (USD 850) and the highest income is Coquimbo (USD 1006). After removing Tirúa from the analyses, there were no significant correlations. After removing Easter Island, the results were similar to when all counties were included. After removing Tirúa and Easter Island, no significant correlations were found.

There were significant positive correlations between SA/mass and average taxable monthly income at 6, 24, 30 months of age and for the overall mean when all counties were included. However, after removing Tirúa, no significant correlations were found, which was confirmed

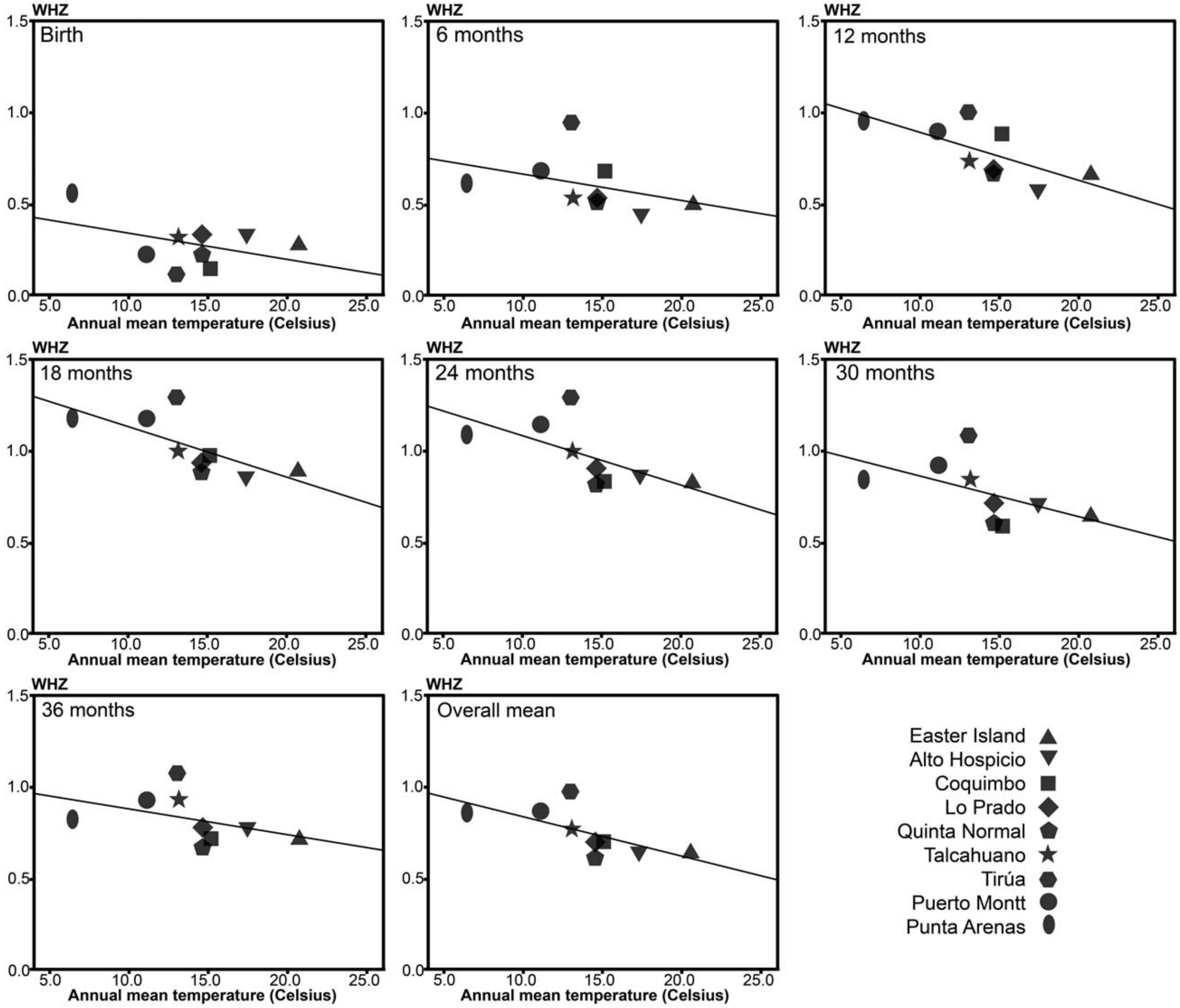

FIGURE 4 Scatter plots and regression lines between WHZ of each county and annual mean temperature by each age interval and in the overall mean of age

after removing Tirúa and Easter Island. When the percentage of poverty was examined in relation to WHZ and SA/mass, practically no significant correlations were found and they were a product of the high percentage of poverty in Tirúa (31.8%) compared with the rest of the counties. After removing Tirúa and Easter Island, no significant correlations were found.

Table 5 presents the partial correlations between WHZ and annual mean temperature and between SA/mass and annual mean temperature after controlling for average taxable monthly income and percentage of poverty. When all counties were included significant negative correlations were found between WHZ and annual mean temperature after controlling for average taxable monthly income at 12, 18, 24, and 30 months of age, as well as in the overall mean. After removing Tirúa, there were significant negative correlations at 12, 18, and 24 months of age, as well as in the overall mean. After removing Easter Island, significant negative correlations were found at 18 and 24 months of age as well as for the overall mean. After removing Tirúa and Easter Island, significant negative correlations were found at 18 and 24 months as well as for the overall mean. Significant negative correlations between WHZ and percentage of poverty were found at 12, 18, 24, 30, 36 months of age, and for the overall mean. Negative correlations remained significant at 18, 24, 30, and 36 months of age, and overall age after removing Tirúa and Easter Island from the analyses.

When all counties were included in the analyses, significant positive correlations between SA/mass and annual mean temperature were found after controlling for average taxable monthly income at 12 and 18 months of age. After removing Tirúa, significant positive correlations were found at 6 and 12 months of age. After removing Easter Island, significant positive correlations were found at 12, 18, 24, and 30 months of age as well as in the overall mean. After removing both Tirúa and Easter Island, significant positive correlations were found at 12, 18, 24, and 30 months of age as well as in the overall mean.

When all counties were included in the analyses, significant positive correlations between SA/mass and annual mean temperature were found after controlling for poverty (%) were found at 6, 12, and 18 months of age, and in the overall mean. After removing Tirúa,

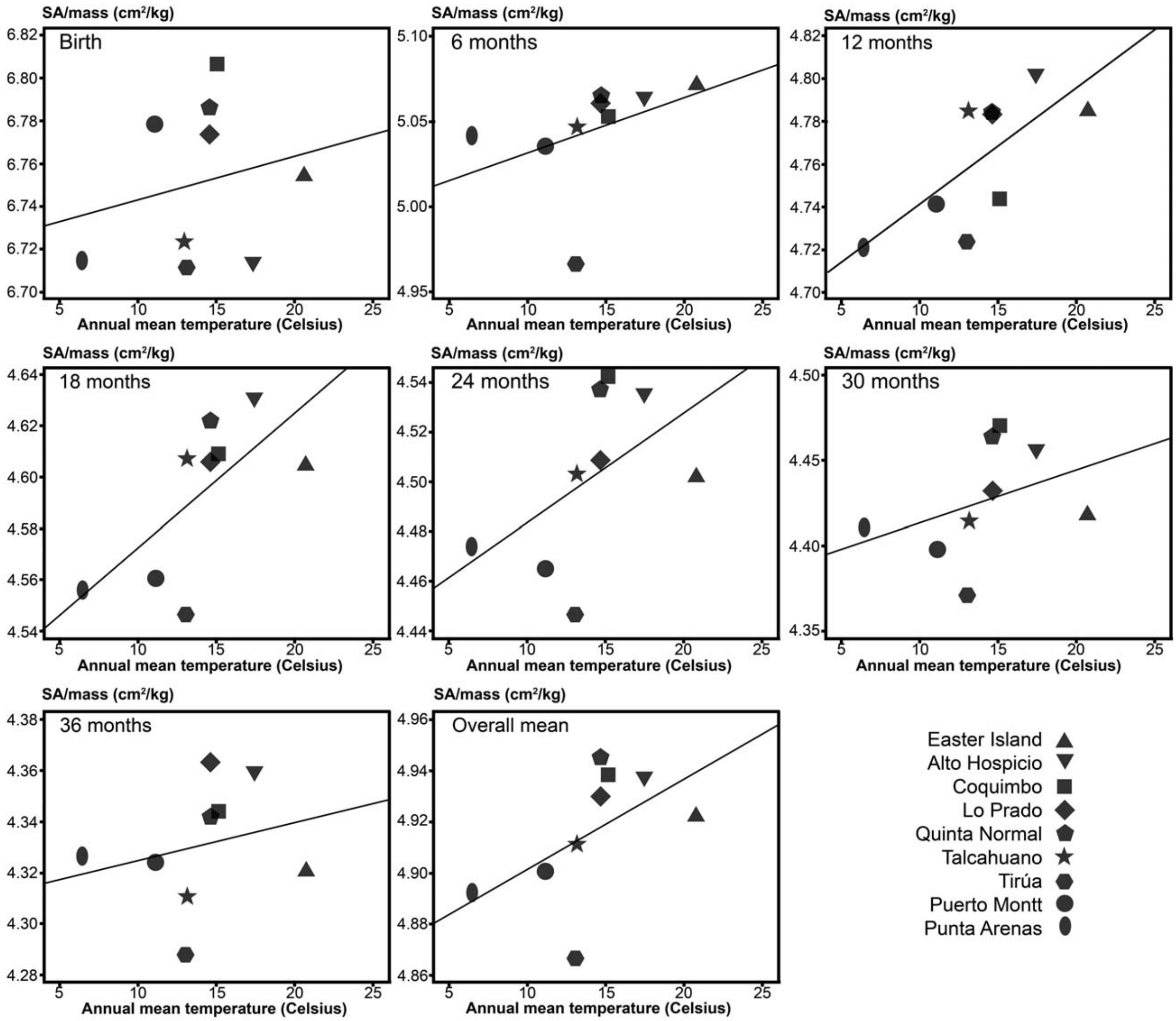

FIGURE 5 Scatter plots and regression lines between SA/mass of each county and annual mean temperature by each age interval and in the overall mean of age

TABLE 4 Pearson correlation coefficients of WHZ and SA/mass with the average taxable monthly income and percentage of poverty (*Significant at $p < 0.05$, **Significant at $p < 0.01$)

		Average taxable monthly income				Percentage of poverty			
	Age	All counties	Removing Tirúa	Removing Easter Island	Removing Tirúa and Easter Island	All counties	Removing Tirúa	Removing Easter Island	Removing Tirúa and Easter Island
WHZ	Birth	0.439	0.039	0.450	−0.021	−0.539	−0.287	−0.543	−0.288
	6 months	−0.772*	0.113	0.761*	0.195	0.555	−0.488	0.549	−0.511
	12 months	−0.449	0.195	−0.416	0.281	0.160	−0.608	0.135	−0.635
	18 months	−0.658	−0.165	−0.640	−0.099	0.337	−0.484	0.322	−0.510
	24 months	−0.764*	−0.420	−0.755*	−0.370	0.491	−0.228	0.486	−0.245
	30 months	−0.792*	−0.518	−0.784*	−0.482	0.584	−0.006	0.583	−0.008
	36 months	−0.781*	−0.442	−0.772*	−0.398	0.685*	0.233	0.691	0.244
	Overall mean	−0.691*	−0.242	−0.677	−0.175	0.424	−0.314	0.415	−0.338
SA/mass	Birth	0.273	0.013	0.272	0.015	−0.421	−0.341	−0.420	−0.341
	6 months	0.886**	0.136	0.885**	0.008	−0.710*	0.266	−0.718*	0.320
	12 months	0.391	−0.203	0.357	−0.276	−0.063	0.687	−0.036	0.709
	18 months	0.591	0.188	0.581	0.175	−0.198	0.601	−0.186	0.604
	24 months	0.687*	0.428	0.700	0.464	−0.339	0.364	−0.340	0.365
	30 months	0.707*	0.425	0.742*	0.503	−0.447	0.171	−0.461	0.175
	36 months	0.628	−0.020	0.682	0.064	−0.540	0.048	−0.567	0.049
	Overall mean	0.717*	0.186	0.716*	0.190	−0.470	0.316	−0.464	0.316

TABLE 5 Partial correlation coefficients of WHZ and SA/mass with annual mean temperature after controlling for average taxable monthly income and percentage of poverty (*Significant at $p < 0.05$, **Significant at $p < 0.01$)

		Annual mean temperature (controlled by average taxable monthly income)				Annual mean temperature (controlled by percentage of poverty)			
	Age	All counties	Removing Tirúa	Removing Easter Island	Removing Tirúa and Easter Island	All counties	Removing Tirúa	Removing Easter Island	Removing Tirúa and Easter Island
WHZ	Birth	−0.555	−0.553	−0.627	−0.650	−0.384	−0.494	−0.451	−0.655
	6 months	−0.439	−0.586	−0.435	−0.517	−0.621	−0.407	−0.642	−0.252
	12 months	−0.715*	−0.812*	−0.743	−0.812	−0.758*	−0.654	−0.796*	−0.623
	18 months	−0.823*	−0.848*	−0.884**	−0.895*	−0.848*	−0.800*	−0.921**	−0.864*
	24 months	−0.829*	−0.829*	−0.867*	−0.867*	−0.874*	−0.825*	−0.939**	−0.899*
	30 months	−0.711*	0.709	−0.741	−0.751	−0.843*	−0.790*	−0.915**	−0.894*
	36 months	−0.528	0.526	−0.487	−0.486	−0.824*	−0.795*	−0.864*	−0.877*
	Overall mean	−0.822*	−0.836*	−0.857*	−0.862*	−0.879*	−0.833*	−0.943**	−0.903*
SA/mass	Birth	0.192	0.201	0.265	0.263	0.356	0.490	0.497	0.750
	6 months	0.623	0.841*	0.577	0.770	0.822*	0.864*	0.851*	0.807
	12 months	0.719*	0.808*	0.769*	0.829*	0.743*	0.634	0.794*	0.614
	18 months	0.744*	0.754	0.934**	0.934**	0.751*	0.643	0.918**	0.862*
	24 months	0.591	0.587	0.920**	0.944**	0.646	0.488	0.909**	0.850*
	30 months	0.400	0.394	0.825*	0.850*	0.545	0.379	0.894**	0.848*
	36 months	0.208	0.249	0.607	0.621	0.445	0.261	0.872*	0.821*
	Overall mean	0.653	0.683	0.894*	0.902*	0.758*	0.649	0.984**	0.973**

significant positive correlations were found at 6 months of age. After removing Easter Island, significant positive correlations were found at 6, 12, 18, 24, 30, and 36 months of age as well as in the overall mean. After removing Tirúa and Easter Island, significant positive correlations were found at 18, 24, 30, and 36 months of age as well as in the overall mean.

4 | DISCUSSION

Chilean children in this study had higher WHZ means from birth to 3 years of age compared with the WHO (2006) growth charts. At 18 months of age, the WHZ mean was nearly one standard deviation above the WHO growth charts although falling to +0.79 SD above the WHO mean at 3 years of age. These results indicate that overweight and obesity in young Chilean children population is of concern. This study also showed that there was considerable heterogeneity in the patterns of mean WHZ between counties from birth to 3 years of age, whilst all counties generally showed an increase from birth to 18 months of age and a slight decrease thereafter. Additionally, there were significant differences in overall means of WHZ between birth and 3 years of age (average of the seven measurements). The results showed a significant negative correlation between WHZ and annual mean temperature of each county especially from 6 months of age onwards. After controlling for average taxable monthly income and the percentage of poverty, there were higher negative correlations between WHZ and annual mean temperature. The removal of Tirúa and Easter Island revealed that some ages did not show significant associations between WHZ and annual mean temperature after controlling for the average taxable mean income, which is possible due to the effect of the low income in Tirúa. After removal of the two counties, significant negative correlations remained between WHZ and annual mean temperature after controlling for the percentage of poverty. This suggests that the removal of these counties with high ethnic component had a small effect on the relationship between WHZ and temperature.

There are few studies that have addressed changes in the nutritional status of young children from a longitudinal perspective in relation to regional or geographical factors. El Mouzan et al. (2009) and Willms et al. (2003) have integrated regional or provincial factors into their studies related to obesity at different ages and different countries. In both of these studies, the authors found that regional factors significantly associate with outcomes. Willms et al. (2003) also found that the significant regional effect could not be entirely explained by adjusting for other variables. The current study also showed that the county of birth effects remained significant after removing other potential confounding variables.

SA/mass between birth and 3 years of age showed a decreasing pattern and a drastic decline during the first year of age, similar to that described by Wells (2000). However, there was considerable heterogeneity in the patterns of overall mean SA/mass between counties. After controlling for the average taxable monthly income and the percentage of poverty, there were higher positive correlations between SA/mass and annual mean temperature. The removal of Easter Island considerably affected the results by revealing higher positive correlations and significance, especially when the percentage of poverty was controlled. As observed in Figure 5, Easter Island showed a lower and decreasing SA/mass ratio from 6 months of age onwards compared with Alto Hospicio and counties from central Chile, which contributed to decrease the correlation between SA/mass and annual mean temperature in this study. As observed by Katzmarzyk and Leonard (1998b), Polynesian adult males and females showed lower SA/mass compared with individuals from other regions sharing similar annual mean temperatures and even lower than individuals from colder regions. This suggests that other factors apart from the annual mean temperature are affecting SA/mass of children from Easter Island, which may be also applicable to Tirúa. More research is needed in order to understand the lower SA/mass of Easter Island and Tirúa children compared with other Chilean children.

It is possible that eco-geographic factors may explain the negative correlation between WHZ and annual mean temperature and the positive correlation between SA/mass and annual mean temperature of each county in Chile, even after controlling for socioeconomic factors. According to Bergmann's rule (Bergmann, 1847), body mass increases with decreasing mean temperature in widely distributed species. The explanation of this rule is that metabolic heat production and thermoregulation in animals is strongly related to body mass. Larger organisms are better adapted to colder environments because they have relatively less surface area through which to lose heat, whilst smaller animals are better suited to warmer environments because they can dissipate heat given their higher surface area (Leonard & Katzmarzyk, 2010). Numerous studies have corroborated this rule in extinct and contemporary adult human populations (Béguelin, 2010; Bergmann, 1847; Foster & Collard, 2013; Fukase et al., 2012; Gilligan & Bulbeck, 2007; Katzmarzyk & Leonard, 1998b; Kurki et al., 2008; Leonard & Katzmarzyk, 2010; Wells, 2000, 2012), showing similar results even though with different magnitudes. The results from the current study suggest that the growth of Chilean children during their first 3 years may be affected by ecogeographic factors such as Bergmann's rule, after controlling for socioeconomic variables. These results suggest that children living in an urban environment can be affected by ecogeographic factors, in spite of cold or heat stress mitigation by technological advances or by being exposed to an obesogenic niche (Wells, 2012). These findings may have implications for the knowledge about growth and adult stature. More research is needed to prove the effect of this ecogeographic factor nowadays. If this factor is proven, it should be controlled before taking into consideration body mass index as a measure of nutritional status in children. Additionally, further analyses should be undertaken to test whether the odds of being overweight or obese in young children are in relation to surface area, as well as geographical or climatic factors. Leonard and Katzmarzyk (2010) warned about the use of BMI for assessing risks of under- and overnutrition in adult population. The results of the current study extend this warning to contemporary children living in urban cities. Altitude is another ecogeographic factor that could affect the variation of weight-for-height or SA/mass in the present study. However, the effect is generally observed in altitudes above ~2,500 m above sea level (Pomeroy et al., 2015), while in the present study the counties with the highest altitude do not exceed 520 m above sea level and most of the counties are coastal (Easter Island, Coquimbo, Talcahuano, Tirúa, Puerto Montt, and Punta Arenas, Figure 3).

While the results of this study suggest the effect of ecogeographic factors on weight-for-height, other untested/unavailable factors may explain the north to south increase in body mass in Chilean children. For example, Dutton and McLaren (2011) observed that sociodemographic variables may show region-specific behaviors, thereby acting unequally on child nutritional status. In Chile some factors which may contribute to regional variability in nutritional status could be the north to south variation in wealth, public health access, food price and related food choice preferences. However, the distribution of wealth, poverty, and public health access in Chile do not follow a north to south orientation. For instance, the highest income per capita, the Index of Human Development and the Index of Socioeconomic Development are concentrated in the few counties from Santiago, while the rest of the counties across Chile show a scattered distribution (Gattini, Chávez, & Albers, 2014). In relation with the access to public health (calculated by the number of people/number of health services in the region or county), southern regions have the better access to health services (1515 to 2691 people per health center), while the rest of the Chilean regions show a scattered distribution without any clear pattern (Biblioteca del Congreso Nacional de Chile, 2015). The Metropolitan region shows the poorest access to health services (9503 people per health service). Taking into consideration only the studied counties, Tirúa showed the highest level of health services (1.59 people per health service), followed by Punta Arenas (4.64), Puerto Montt (5.28), Easter Island (5.76), Coquimbo (9.78), Talcahuano (12.26), Quinta Normal (14.5), Alto Hospicio (18.76), and Lo Prado (22.93). There was not a significant correlation between the level of health services by each county and the latitude, weight-for-height, and SA/mass among the studied counties.

In terms of food price and related food choice preferences, Katzmarzyk and Leonard (1998b) argued that climate may shape body morphology through its influence on food availability and nutrition. In Chile, Ivanovic (2004, 2013) observed that lower social status households from Punta Arenas chose to eat smaller amounts and less variety of vegetables due to a combination of their price, taste, lack of knowledge and time for preparation. In contrast, Easter Island has an abundance of marine resources, which are distributed through formal and informal transactions (Montecino, 2010). Therefore, the low weight-for-height found in Easter Island may be associated to their better socio-economic conditions, a favorable environment, and better social capital (Ulijaszek, Mann, & Elton, 2012).

Additionally, the interaction between household occupation and county of birth may exert an effect on nutritional status. For instance, according to Ivanovic (2004) the majority of women in Punta Arenas have waged occupations outside their home which may reduce the breastfeeding period and duration. Several studies have shown that maternal education has differential effects on child health depending on regional and contextual factors (Behrman & Wolfe, 1987; Muhuri, 1995; Raghupathy, 1996; Rosenzweig & Schultz, 1982; Sastry, 1997). Finally, behaviors, traditions, and beliefs pertaining to each county may impact on food and physical activity habits. For instance, Punta Arenas people have dietary preferences through a high intake of fat and fried dough, few vegetables and appreciate a more robust body ideal (Ivanovic, 2004). Additionally, some counties showed deviation from the predictive line of WHZ, such as Tirúa and Punta Arenas. Tirúa is a county with a high percentage of indigenous population, which may explain the different trend of weight gain through ethnic, cultural or social factors. In Punta Arenas, it is possible that cold stress may be mitigated by the heating system such as natural gas, which is subsided by the Chilean government in that county.

5 | CONCLUSIONS

This study has shown that there is considerable heterogeneity in the patterns of mean WHZ and SA/mass between counties from birth to 3 years of age. Colder counties have higher WHZ and lower SA/mass means compared with warmer counties. This regional variation in body mass and surface area remained after controlling for a number of potential confounders such as household occupation, birth order, sex of the child, year of birth, age of the mother, age of cessation of receiving breast milk, age of commencement of formula-based milk, and age of commencement of giving other types of food, as well as the average taxable monthly income and the percentage of poverty. The mean temperature cline in WHZ and SA/mass suggests the association of ecogeographic factors such as Bergmann's rule, while other socioeconomic factor may also explain these gradients. Thus, a much more comprehensive study is needed to be able to differentiate the body mass/temperature and surface area/temperature association from confounders.

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