Statistical challenges in observational cohort studies

Hof, M.H.P.

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6 Comparison of growth between native and immigrant infants between 0-3 years from the Dutch ABCD cohort

In the Netherlands separate reference charts have been developed for native and immigrant groups to deal with differences in growth patterns in later childhood. The use of these charts however is complicated by methodological issues; they do not represent all large Dutch immigrant groups in separate charts despite the differences that have been suggested and the evidence of ethnic disparities in growth dates back to 1997. Anthropometric measurements from a contemporary multi-ethnic cohort study were created to quantify differences in childhood growth by creating growth charts, separately for boys and girls between the ages of 0-3 years. The infants modeled in the charts had a mother born in the Netherlands ($n = 3107$), Suriname ($n = 225$), Turkey ($n = 203$), and Morocco ($n = 336$). Charts with and without correction for country of origin of the mother were created by using the LMST method. All models including the covariate country of origin of the mother fitted the data better ($p < 0.0005$), but the observed differences were small. Most remarkable differences were found in the BMI and weight measurements for age charts. Especially girls from mothers born in Turkey and Morocco had an increasingly heavier weight for their age than girls from mothers born in the Netherlands.

Introduction

Growth assessment is a useful tool for monitoring the development of a child. Anthropometric measurements of the child are compared to an acceptable set of reference values in order to detect abnormal growth patterns. Because disturbances in health and nutrition almost always have an impact on growth, this method is widely accepted and implemented [136].

Reference growth charts for Dutch children between 0-4 years of age were recently published by the Dutch organization for applied natural science, based on growth measurements from the fifth Dutch nation-wide survey [137]. Similarly to the reference charts based on data from the fourth Dutch nation-wide survey conducted in 1997, separate charts have been developed for children with a native Dutch background as well as for Moroccan, and Turkish immigrant groups [138].

These separate charts were made because the fourth Dutch nation-wide survey showed that children from parents of Moroccan and Turkish origin are relatively heavier and shorter than children from parents of Dutch origin. Furthermore different developmental patterns in growth were observed due to the difference in initiation and duration of puberty [46, 45].

Surprisingly, no separate reference charts for Dutch children from parents of Surinamese origin exist despite the observed differences in their birth weight compared to children from parents of Dutch origin. It has been recently confirmed that birthweight, an important determinant of infant growth, is different between native Dutch children and immigrant groups. In the Netherlands, Goedhart et al. [139] as well as Troe et al. [140] showed that children with a Surinamese, Antillean, and Ghanaian background were smaller at birth than Dutch children. Despite the correlation between weight at birth and weight in infancy [141] no separate reference charts have been developed for these immigrant groups.

Recently the world health organization (WHO) also published new growth charts for children between 0-5 years of age developed with data from the Multicentre Growth Reference Study (MGRS) [142, 143]. Contradictory to the Dutch reference growth charts one general growth curve was modeled from the growth measurements collected in six countries. Their data showed that under favorable conditions the linear growth curve of height of the children was similar regardless of their country of origin.

The aim of our study was to measure whether there are differences in normal growth between infants with a Dutch background and infants from Dutch immi-

grant groups. The evidence that these differences exist is based on data from 1997 and not all large immigrant groups were included in this analysis. In addition, the WHO recommends using their reference chart for each infant, regardless of the country of origin of their parents. Separate growth charts for infants from mothers born in the Netherlands and for infants from mothers born in Turkey, Morocco, and Surinamese living in Amsterdam between 0-3 years were modeled to measure the differences. We used data from the Amsterdam Born Children and their Development (ABCD) study. The five most frequently used measures of growth were modeled (height for age, weight for age, BMI for age, head circumference for age, and weight for height), all separately for boys and girls.

Methods

In order to create the reference charts growth measurements from the prospective Amsterdam Born Children and their Development (ABCD) study population were used. The ABCD study focuses on lifestyle and characteristics of the mother during pregnancy in relation to the development of the child, with specific interest on ethnic differences [139, 144, 11].

Between January 2003 and March 2004, all pregnant women living in Amsterdam (n = 12373) were invited to participate in the study at their first visit to an obstetric caregiver. A language specific questionnaire was sent two weeks after this visit to the pregnant women's home address covering sociodemographic data, obstetric history, lifestyle, dietary habits, and psychosocial factors. Reminders were sent two weeks later to all non-responders. Questionnaires were returned by 8266 women (67%), from which 6575 (80%) gave permission to collect growth data on their child.

Subsequently, data was routinely collected at the Youth Health Care registration of the Public Health Service in Amsterdam until the child reached the age of 3 years. On average children were measured by trained nurses at 9 regular follow-up moments. Since the ABCD project started in 2003 the first two phases of the study - registering the characteristics during pregnancy and the development of the infant - have been completed. Data from these phases was used for this article [145].

For the current study, digitized data of one or more measurement(s) was available for 4850 singleton children. Since the previous reference charts had been developed for healthy children, all preterm children (pregnancy duration shorter

Boys

Age (weeks)	Ethnic Group				Total
	Dutch (n=1512)	Surinamese (n=117)	Turkish (n=106)	Moroccan (n=183)	
0 - 12	4653	347	353	598	5951
13 - 38	4949	406	370	643	6368
39 - 64	2741	221	189	342	3493
65 - 90	939	78	64	114	1195
91 - 116	641	47	46	76	810
117 - 142	419	40	29	62	550
143 - 156	94	1	12	19	126
Total	14436	114	1063	1854	18493

Girls

Age (weeks)	Ethnic Group				Total
	Dutch (n=1459)	Surinamese (n=97)	Turkish (n=93)	Moroccan (n=145)	
0 - 12	383	248	257	425	476
13 - 38	4217	305	277	448	5247
39 - 64	238	170	159	239	2948
65 - 90	812	58	63	70	1003
91 - 116	570	33	32	47	682
117 - 142	372	21	29	48	470
143 - 156	60	4	7	20	91
Total	12241	839	824	1297	15201

Table 6.1: Number of growth measurements available from the ABCD dataset per age period and modelled group, separately for boys and girls.

than 37 weeks) were excluded. The distinction between children with a Dutch background and children from Dutch immigrant groups was made by using the definition of 'immigrant' used by the Dutch governmental statistics office (Statistics Netherlands): a child is considered to be non-Dutch when the mother has not been born in the Netherlands [146]. Children of all first generation mothers were thus assigned to the non-Dutch groups. Children of second generation mothers were assigned to the Dutch group.

The Dutch ($n = 3107$) group and the Surinamese ($n = 225$), Turkish ($n = 203$), and Moroccan ($n = 336$) immigrant groups were included in the analysis. Unfortunately, the Antillean ($n = 46$) and Ghanaian ($n = 95$) groups were too small which prevented us from modeling their growth charts. Most measurements were performed within the first six months after birth (table 6.1). Weight was always recorded at birth; the other variables only incidentally. Head circumference was measured until the age of 12 months; all other characteristics were measured until the age of three years.

The LMST method was used to generate the reference curves. This method assumes that growth data can be transformed with a Box-Cox power transformation to fit a desired distribution [147]. With this method a growth-variable is modeled with an almost nonparametric but smooth function of age.

In particular, we used the Box-Cox-t power formula to transform the data to fit a t-distribution [148]. Firstly, the power formula transformed the growth-measurements Y into a new variable Z using a Box-Cox-t transformation with the transform power parameter ν, such that the conditional distribution of Z was approximately symmetrically distributed. Next, both the mean μ and the log of the standard deviation σ were modeled with a cubic spline of age x. We finally assumed that the transformed growth-variable was t-distributed with τ degrees of freedom. The Box-Cox-t transformation used the following formula

$$Z(x) = \begin{cases} \frac{1}{\sigma(x)\nu}\left[\left(\frac{Y}{\mu(x)}\right)^{\nu} - 1\right] & \text{if } \nu \neq 0, \\ \frac{1}{\sigma(x)}\left[\left(\frac{Y}{\mu(x)}\right)\right] & \text{if } \nu = 0. \end{cases} \tag{6.1}$$

By using the inverse of the Box-Cox-t power formula the values could be transformed to fit the original data. The parameters $(\mu(x), \sigma(x), \nu, \tau)$ were estimated by maximizing the log-likelihood of the data.

The reference charts were made with the statistical program R [84]. The LMST method with the Box Cox-t power transformation is implemented by the GAMLSS package [149]. The GAMLSS package has the possibility to include random factors in the model which may be used to account for the covariance between repeated assessments in the children. However, in our analysis the random term was not significant which we attributed to the strong dependence of growth on age. Therefore we did not include these random factors in the model.

The mean and standard deviation at age x, $\mu(x)$ and $\sigma(x)$, (or at height x in case of weight for height) were modeled with cubic splines. The optimal degrees of freedom of the cubic spline models were found by minimizing the Akaike Information Criterion (AIC) (table 6.2). This was done in a stepwise manner; first by modeling $\mu(x)$ and then $\sigma(x)$. Cubic spline models were also fitted for $\tau(x)$ and $\nu(x)$, but these parameters turned out to be independent of age (and height). Therefore τ and ν were considered to be constant over age.

Growth chart		$\mu(x)$	$\sigma(x)$
Height for Age			
	Boys	4	3
	Girls	4	3
Weight for Age			
	Boys	11	4
	Girls	10	4
Body Mass Index for Age			
	Boys	6	2
	Girls	6	1
Head circumference for Age			
	Boys	8	7
	Girls	8	8
Weight for Height			
	Boys	8	6
	Girls	5	6

Table 6.2: Degrees of freedom used in the cubic splines describing the relation in the reference charts. Both (mean) and (standard deviation) for both models were modeled with cubic splines having the best degrees of freedom to describe the data.

To test whether $\mu(x)$, $\sigma(x)$, τ, and ν differed between the Dutch and immigrant groups, two models were fitted to the data. Models with and without the covariate 'country of origin of the mother' including interaction with age, were created and compared on model fit using the Bayesian Information Criterion (BIC).

The models that were used to predict the parameters were based on the following equations:

- Without country of origin of the mother;
  variable $Y \sim$ variable x

- With country of origin of the mother;
  variable $Y \sim$ variable x + country of origin of the mother + (country of origin of the mother $\times$ variable x)

where variable Y is one of the five anthropometric measures and variable x is either age or height. The interaction (country of origin of the mother $\times$ variable x) denotes the possibility that the shape of the relationship between variable x and variable Y differs between the different groups. Separate models were created for boys and girls. A likelihood-ratio test was used to test whether the differences were statistically significant.

In addition to this analysis two other sub-analyses were performed. Firstly, the average BMI for age for the children from the ABCD cohort was compared to the current WHO 2010 standard (version 3.1, June 2010). Secondly, characteristics from the mothers that might influence the development of their child were included in the models to measure their impact. These characteristics were height of the mother, weight of the mother, age of the mother, and the mother's smoking status. These covariates were included in the height for age, weight for age, and BMI for age charts and a multivariate analysis was used to measure their impact and significance.

Results

Overall analysis

All the tables and figures regarding the comparison of the children with a Dutch and an immigrant background are located at the end of the results section. Comparing the models using the likelihood ratio test, all models including the added covariate country of origin of the mother and its interaction with age or height fitted the data significantly better ($p < 0.0005$) than the models without the covariate. But the BIC was only lower for the BMI for age model with the added covariate, with similar results for both genders. In the other growth charts the BIC was higher in the models with the covariate (table 6.3).

Comparison of normal growth between children with a Dutch and an immigrant background

Details of all reference charts are given in tables 6.4, 6.5 and 6.6. The extent of deviation from the normal distribution is given by the τ, and ν parameters is given in table 6.4 and the fitted growth curves are given in tables 6.4 and 6.5. Since almost none of the transformed growth data was normally distributed we described the variation in growth with quantile scores.

The differences between children with a Dutch and an immigrant background in all reference charts will now be summarized.

Height for age

Only small differences were found for both genders in height development for the four groups. Infants from the Turkish, Surinamese, and Moroccan immigrant groups were born slightly shorter than infants from the Dutch group. These differences disappeared around the age of 26 weeks. After 104 weeks the growth patterns of girls from the Turkish and Surinamese groups began to deviate from the girls from the Dutch group: girls from Turkish mothers grew faster and girls from Surinamese mothers grew slower. This difference was not observed for boys (figure 6.1).

Weight for age

Differences in weight between the Dutch and immigrant groups were observed over all ages. Children from the Surinamese group had lower birth weights compared to children from the Dutch group. Children from the Dutch, Turkish, and Moroccan groups had similar birth weights.

After 40 weeks the difference between the Dutch, Turkish, and Moroccan groups started to increase. Especially girls from the Turkish and Moroccan groups were becoming increasingly heavier. At the age of 3 years they were approximately one kilogram heavier than the Dutch girls. The development of girls from the Surinamese group followed the pattern of the girls from the Dutch group up to the age of 104 weeks. After this period the increase in weight was not as fast as in the girls from the Dutch group.

Between the boys from the Dutch, Moroccan, and Turkish group only small birth weight differences were present. Boys from the Surinamese group were born lighter and remained lighter during the observed period of three years. Similar to girls, boys from the Moroccan and Turkish group remained heavier than the other groups. At the age of 3 years they were about 500 gram heavier than the boys from the Dutch group (figure 6.2).

BMI for age

The relatively large differences in weight compared to the small differences in height were reflected in the BMI for both genders. Infants from the Dutch and Surinamese groups had similar BMIs during their development. In these children, the BMI peaked at 52 weeks and declined afterwards. Infants from the Moroccan and Turkish groups had a higher BMI at all ages. In addition, the decline in BMI after 52 weeks weeks was smaller in these groups, compared to the Dutch and Surinamese group. This phenomenon was more pronounced in girls (figure 6.3).

Head circumference for age

No large differences between the Dutch and immigrant groups were found in the development of the head circumference. Similar to height development, infants with mothers from Surinamese origin had smaller head circumferences and infants from the Moroccan and Turkish groups followed the same development pattern as the infants from the Dutch group (figure 6.4).

Weight for height

Infants from the Moroccan and Turkish groups had similar weight for height reference charts. Compared to infants from the Dutch group these groups were relatively heavier for their height. Infants from the Surinamese group had similar weights compared to the Moroccan and Turkish groups up to the height of 70 centimeters. After this point the infants from the Surinamese group became lighter for their height (figure 6.5).

Comparison of BMI between children from the ABCD cohort and the WHO growth standard

All groups from the ABCD cohort had a higher BMI for age compared to the WHO growth standard from the age of approximately 52 weeks for both boys and girls. The peak in BMI also occurred somewhat later for the ABCD cohort children for both genders. In the WHO growth standard this peak was located around the age of 30 weeks where the peak in BMI in the ABCD cohort was observed at 52 weeks of age (figure 6.6). In addition the peak in BMI was higher for the ABCD cohort children and afterwards their growth curve gradually converged to the WHO standard but remained higher.

Analysis of the impact of the mother's characteristics on the development of the child

Characteristics of the mothers were reported elsewhere [139]. In short, mothers with a Surinamese, Turkish, and Moroccan background were slightly shorter than the mothers from the Dutch group. Also the BMI of the Surinamese, Turkish, and Moroccan mothers was more frequently abnormal compared to mothers from the Dutch group. In addition, mothers with a Moroccan background smoked less than mothers from the other groups.

In our analysis height and weight of the mother was significantly positively associated with the height and weight of their children (table 6.7), and mothers who smoked had significantly smaller and lighter children. The differences between the growth curves of the different groups remained significant after adjustment for the effects of the characteristics of the mothers.

Growth Chart		Without correction for ethnicity			With correction for ethnicity			Likelihood ratio test
		Log-likelihood	Degrees of freedom	BIC	Log-likelihood	Degrees of freedom	BIC	
Height for Age								
	Boys	-37211	11	74528	-37105	44	74634	$p < 0.0005$
	Girls	-36265	11	72635	-36147	44	72717	$p < 0.0005$
Weight for Age								
	Boys	-155413	19	311012	-155246	76	311237	$p < 0.0005$
	Girls	-151881	18	303938	-151618	72	303942	$p < 0.0005$
BMI for Age								
	Boys	-28296	12	56718	-28058	48	56579	$p < 0.0005$
	Girls	-27172	11	54451	-26879	44	54182	$p < 0.0005$
Head Circumference for Age								
	Boys	-16585	19	33345	-16412	76	33526	$p < 0.0005$
	Girls	-15435	20	31054	-15368	80	31473	$p < 0.0005$
Weight for Height								
	Boys	-81969	18	164105	-81772	72	164211	$p < 0.0005$
	Girls	-77789	15	155716	-77607	60	155767	$p < 0.0005$

Table 6.3: Log-likelihoods for the reference models with and without correction for ethnicity. The difference between the log-likelihoods is tested with a likelihood-ratio test, from which the two-sided p-values are presented. In addition the Bayesian information criterion is also given. The degrees of freedom of the models are equal to the number of parameters in the spline functions that describe the mean and the variance (see table 6.2) plus one parameter for the skewness, one parameter for the transformation, one parameter for the intercept, and one parameter for the residual variance.

Height for Age

	skewness (ν)		kurtosis (τ)	
	Boys	Girls	Boys	Girls
Dutch	1.63 (0.20)	0.14 (0.21)	16.99 (1.52)	12.1 (0.79)
Surinamese	1.39 (0.72)	-2.74 (0.76)	24.52 (11.02)	14.87 (4.57)
Turkish	0.10 (0.83)	-2.54 (0.75)	7.21 (1.15)	1.63×10^5 (1.09×10^5)
Moroccan	0.67 (0.61)	0.34 (0.61)	12.38 (2.36)	2.30×10^5 (8.70×10^5)

Weight for Age

	skewness (ν)		kurtosis (τ)	
	Boys	Girls	Boys	Girls
Dutch	0.45 (0.06)	0.04 (0.06)	25.05 (2.94)	24.07 (2.7)
Surinamese	-0.49 (0.19)	0.22 (0.20)	26.68 (11.77)	7.11×10^5 (9.98×10^5)
Turkish	0.64 (0.21)	-0.08 (0.19)	8.16 (1.32)	3.86×10^5 (1.00×10^6)
Moroccan	0.30 (0.16)	0.74 (0.06)	40.39 (20.97)	10.66 (1.79)

BMI for Age

	skewness (ν)		kurtosis (τ)	
	Boys	Girls	Boys	Girls
Dutch	-0.23 (0.09)	-0.08 (0.09)	13.58 (1.00)	21.79 (2.42)
Surinamese	-0.91 (0.26)	0.21 (0.30)	96.98 (162.03)	114.75 (240.34)
Turkish	-0.4 (0.27)	-0.09 (0.31)	166.63 (491.94)	13.45 (3.78)
Moroccan	0.08 (0.21)	0.54 (0.27)	35.13 (17.34)	15.92 (4.15)

Head Circumference for Age

	skewness (ν)		kurtosis (τ)	
	Boys	Girls	Boys	Girls
Dutch	-0.53 (0.32)	0.75 (0.34)	17.02 (1.9)	10.07 (0.71)
Surinamese	-0.58 (1.04)	-0.14 (1.15)	8.4 (1.82)	3.75×10^{10} (1.37×10^6)
Turkish	-4.42 (1.13)	-4.24 (1.27)	19.15 (8.92)	8.22 (1.53)
Moroccan	2.16 (0.92)	1.00 (1.11)	14.37 (3.95)	21.65 (12.03)

Weight for Height

	skewness (ν)		kurtosis (τ)	
	Boys	Girls	Boys	Girls
Dutch	-0.27 (0.11)	-0.37 (0.11)	13.42 (1.21)	17.16 (1.92)
Surinamese	-0.22 (0.32)	0.20 (0.37)	3.60×10^7 (1.26×10^6)	535.68 (5759.56)
Turkish	-0.33 (0.35)	0.25 (0.41)	163.25 (567.86)	29.31 (21.64)
Moroccan	-0.14 (0.27)	0.61 (0.33)	19.3 (6.79)	55.09 (57.71)

Table 6.4: Modeled skewness parameter ν and degrees of freedom τ for the Student-t distribution after transformation of the data. Values are described as estimated parameter (standard error). The data is approximately normally distributed if the parameter ν is zero and the τ parameter reaches infinity.

	Age (weeks)	Dutch (n=1512)	Surinamese (n=117)	Turkish (n=106)	Moroccan (n=183)
Height for Age	0	52 (0.09)	50 (0.35)	51 (0.29)	51 (0.25)
	26	68 (0.03)	68 (0.12)	68 (0.12)	68 (0.09)
	52	77 (0.04)	76 (0.15)	77 (0.16)	77 (0.11)
	78	83 (0.06)	82 (0.23)	83 (0.26)	83 (0.18)
	104	88 (0.07)	87 (0.25)	86 (0.27)	88 (0.20)
	156	97 (0.22)		97 (0.73)	96 (0.56)
	Age (weeks)	Dutch (n=1512)	Surinamese (n=117)	Turkish (n=106)	Moroccan (n=183)
BMI for Age	0	13.44 (0.09)	13.10 (0.39)	13.52 (0.39)	13.87 (0.27)
	26	17.07 (0.03)	17.08 (0.10)	17.71 (0.11)	17.77 (0.09)
	52	17.38 (0.03)	16.92 (0.12)	17.62 (0.13)	17.71 (0.10)
	78	16.90 (0.03)	16.47 (0.14)	17.21 (0.14)	17.20 (0.11)
	104	16.48 (0.03)	16.00 (0.14)	16.93 (0.18)	16.88 (0.12)
	156	15.83 (0.09)		16.40 (0.37)	16.60 (0.28)
	Age (weeks)	Dutch (n=1512)	Surinamese (n=117)	Turkish (n=106)	Moroccan (n=183)
Head Circumference for Age	6	38.8 (0.04)	38.3 (0.14)	38.7 (0.11)	39.1 (0.10)
	16	42.0 (0.03)	41.5 (0.12)	41.6 (0.12)	42.2 (0.09)
	26	44.1 (0.03)	43.4 (0.14)	43.7 (0.12)	44.4 (0.09)
	36	45.6 (0.04)	44.6 (0.15)	45.4 (0.15)	45.9 (0.12)
	46	46.7 (0.04)	45.7 (0.15)	46.2 (0.14)	47 (0.11)
	Age (weeks)	Dutch (n=1512)	Surinamese (n=117)	Turkish (n=106)	Moroccan (n=183)
Weight for Age	0	3584 (14)	3358 (46)	3476 (45)	3594 (33)
	26	8028 (23)	7850 (87)	8367 (101)	8242 (69)
	52	10192 (27)	9690 (99)	10397 (112)	10367 (81)
	78	11612 (32)	11112 (124)	11818 (131)	11847 (104)
	104	12883 (42)	12200 (170)	13015 (206)	13080 (137)
	156	14778 (134)		15385 (486)	15392 (320)
	Height (cm)	Dutch (n=1512)	Surinamese (n=117)	Turkish (n=106)	Moroccan (n=183)
Weight for Height	55	4530 (13)	4643 (47)	4726 (48)	4742 (37)
	60	5836 (14)	6061 (60)	6167 (56)	6045 (40)
	65	7090 (19)	7174 (80)	7304 (83)	7317 (67)
	70	8406 (19)	8324 (81)	8791 (96)	8750 (72)
	75	9826 (23)	9499 (90)	9939 (109)	10032 (84)

Table 6.5: Male reference values derived from the models correcting for the mother's country of birth describing all five relations. Values are described as mean (standard error).

	Age (weeks)	Dutch (n=1459)	Surinamese (n=97)	Turkish (n=93)	Moroccan (n=145)
Height for Age	0	51 (0.09)	49 (0.39)	50 (0.37)	50 (0.28)
	26	67 (0.03)	66 (0.13)	67 (0.13)	66 (0.10)
	52	75 (0.04)	75 (0.16)	76 (0.15)	75 (0.12)
	78	81 (0.06)	81 (0.25)	82 (0.22)	82 (0.19)
	104	87 (0.07)	86 (0.28)	88 (0.25)	87 (0.21)
	156	96 (0.22)	94 (0.86)	98 (0.75)	96 (0.50)
	Age (weeks)	Dutch (n=1459)	Surinamese (n=97)	Turkish (n=93)	Moroccan (n=145)
BMI for Age	0	13.66 (0.08)	12.84 (0.36)	13.39 (0.31)	13.54 (0.24)
	26	16.62 (0.02)	16.90 (0.10)	17.33 (0.11)	17.40 (0.08)
	52	16.87 (0.03)	16.78 (0.12)	17.67 (0.14)	17.58 (0.10)
	78	16.49 (0.03)	16.45 (0.13)	17.20 (0.16)	17.20 (0.11)
	104	16.18 (0.03)	16.02 (0.14)	16.93 (0.18)	17.01 (0.12)
	156	15.75 (0.10)	14.90 (0.40)	16.80 (0.48)	16.99 (0.29)
	Age (weeks)	Dutch (n=1459)	Surinamese (n=97)	Turkish (n=93)	Moroccan (n=145)
Head Circumference for Age	6	37.9 (0.04)	37.4 (0.13)	38.1 (0.11)	37.9 (0.11)
	16	40.9 (0.03)	40.6 (0.12)	41.1 (0.11)	40.9 (0.08)
	26	42.9 (0.03)	42.5 (0.14)	42.9 (0.13)	43.0 (0.10)
	36	44.3 (0.04)	44.1 (0.14)	44.4 (0.15)	44.4 (0.11)
	46	45.4 (0.04)	45.0 (0.15)	45.5 (0.16)	45.7 (0.11)
	Age (weeks)	Dutch (n=1459)	Surinamese (n=97)	Turkish (n=93)	Moroccan (n=145)
Weight for Age	0	3455 (13)	3211 (49)	3403 (48)	3400 (38)
	26	7358 (20)	7382 (81)	7769 (92)	7682 (62)
	52	9409 (21)	9417 (87)	10093 (102)	9906 (64)
	78	10908 (29)	11021 (126)	11628 (141)	11435 (90)
	104	12204 (39)	12098 (184)	13015 (207)	12956 (128)
	156	14398 (133)	13145 (6432)	16061 (631)	15475 (340)
	Height (cm)	Dutch (n=1459)	Surinamese (n=97)	Turkish (n=93)	Moroccan (n=145)
Weight for Height	55	4490 (9.47)	4629 (45.17)	4700 (39)	4636 (29)
	60	5668 (11)	5889 (51)	5944 (45)	5974 (37)
	65	6933 (13)	7043 (60)	7262 (59)	7271 (43)
	70	8236 (15)	8285 (61)	8532 (73)	8565 (58)
	75	9520 (22)	9477 (79)	9978 (107)	9811 (78)

Table 6.6: Female reference values derived from the models correcting for the mother's country of birth describing all five relations. Values are described as mean (standard error).

Height for Age

	Mother's height		Mother's weight		Mother's age		Mother's smoking status	
	Impact (per cm.)	p-value	Impact (per kg.)	p-value	Impact (per year)	p-value	Impact (yes)	p-value
Boys	0.095 (0.003)	< 0.0005	0.016 (0.002)	< 0.0005	-0.005 (0.004)	0.159	-0.597 (0.056)	< 0.0005
Girls	0.090 (0.003)	< 0.0005	0.019 (0.002)	< 0.0005	-0.002 (0.003)	0.603	-0.207 (0.056)	< 0.005

Weight for Age

	Mother's height		Mother's weight		Mother's age		Mother's smoking status	
	Impact (per cm.)	p-value	Impact (per kg.)	p-value	Impact (per year)	p-value	Impact (yes)	p-value
Boys	14.6 (0.9)	< 0.0005	9.9 (0.5)	< 0.0005	-2.9 (1.1)	< 0.05	-140.1 (16.2)	< 0.0005
Girls	16.4 (0.9)	< 0.0005	9.0 (0.5)	< 0.0005	-0.7 (1.0)	0.656	-32.9 (15.7)	< 0.05

BMI for Age

	Mother's height		Mother's weight		Mother's age		Mother's smoking status	
	Impact (per cm.)	p-value	Impact (per kg.)	p-value	Impact (per year)	p-value	Impact (yes)	p-value
Boys	-0.009 (0.002)	< 0.0005	0.016 (0.001)	< 0.0005	-0.011 (0.002)	< 0.0005	0.050 (0.034)	0.143
Girls	0.000 (0.002)	0.831	0.015 (0.001)	< 0.0005	-0.008 (0.002)	< 0.005	0.218 (0.034)	< 0.0005

Table 6.7: Multivariate analysis of the impact of the characteristics of the mother on the development of their child. These covariates are added to the models describing height, weight, and BMI for age. Values are described as regression coefficients (standard error).

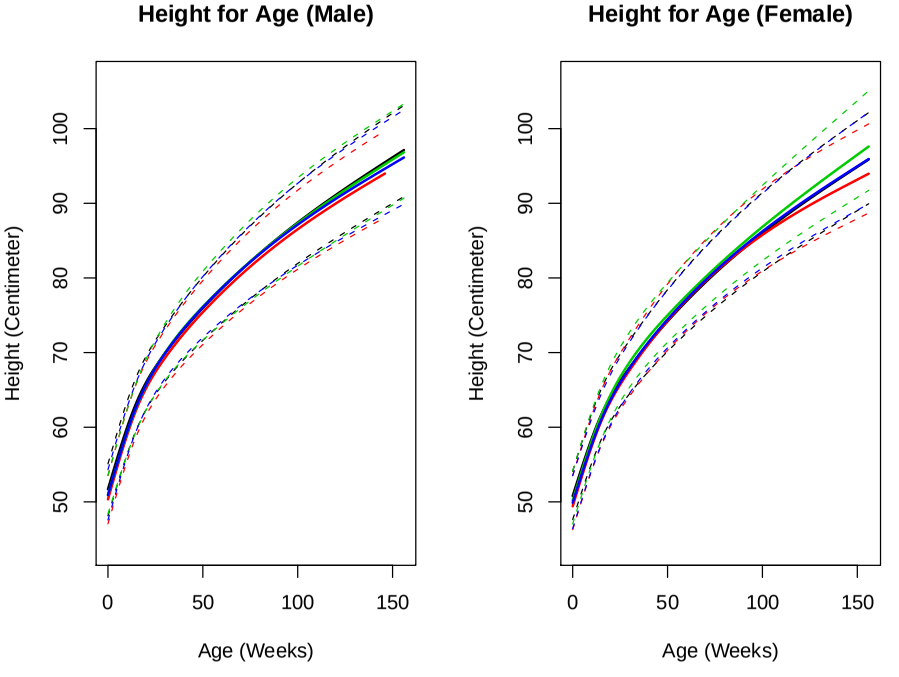

Figure 6.1: Growth charts describing height for age. In these charts the black line represents the Dutch group, the red line the Surinamese group, the green line the Turkish group, and the blue line the Moroccan group. The continuous line describes the mean and the dotted lines the 5% and 95% percentiles of the distribution of the measurements.

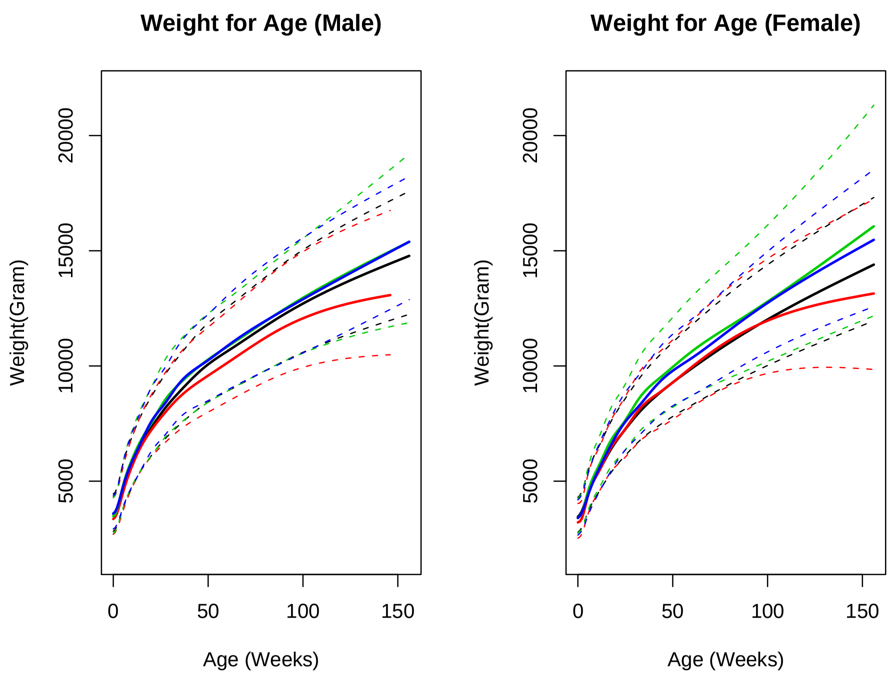

Figure 6.2: Growth charts describing weight for age. In these charts the black line represents the Dutch group, the red line the Surinamese group, the green line the Turkish group, and the blue line the Moroccan group. The continuous line describes the mean and the dotted lines the 5% and 95% percentiles of the distribution of the measurements.

IV

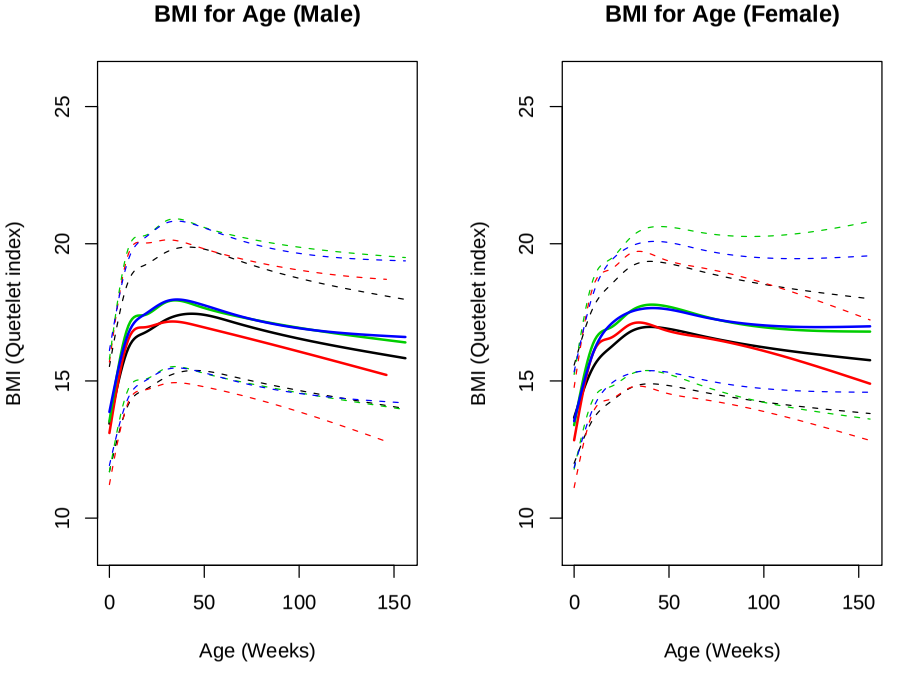

Figure 6.3: Growth charts describing BMI for age. In these charts the black line represents the Dutch group, the red line the Surinamese group, the green line the Turkish group, and the blue line the Moroccan group. The continuous line describes the mean and the dotted lines the 5% and 95% percentiles of the distribution of the measurements.

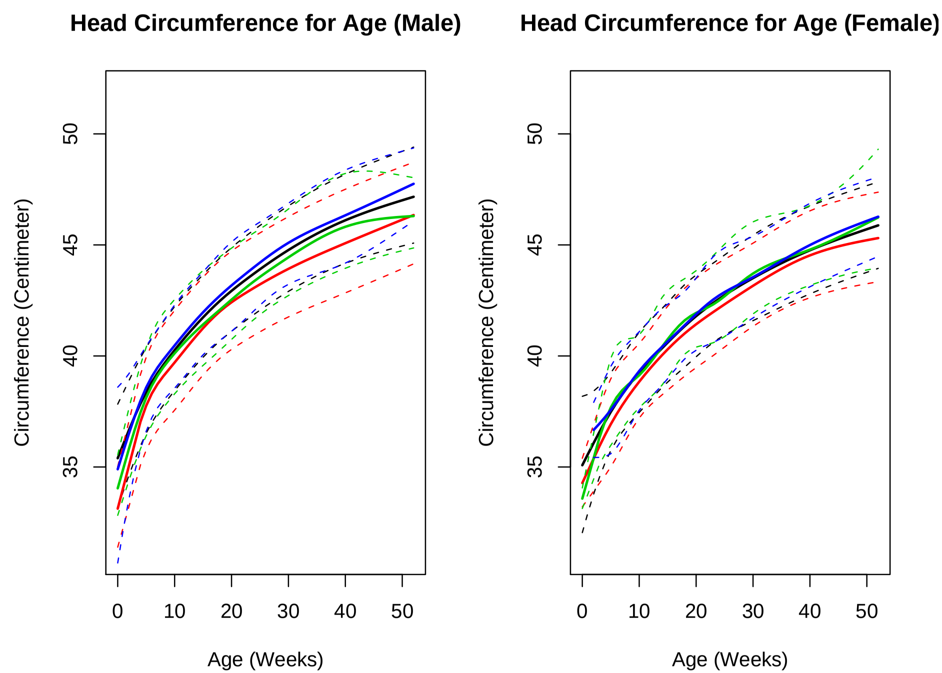

Figure 6.4: Growth charts describing head circumference for age. In these charts the black line represents the Dutch group, the red line the Surinamese group, the green line the Turkish group, and the blue line the Moroccan group. The continuous line describes the mean and the dotted lines the 5% and 95% percentiles of the distribution of the measurements.

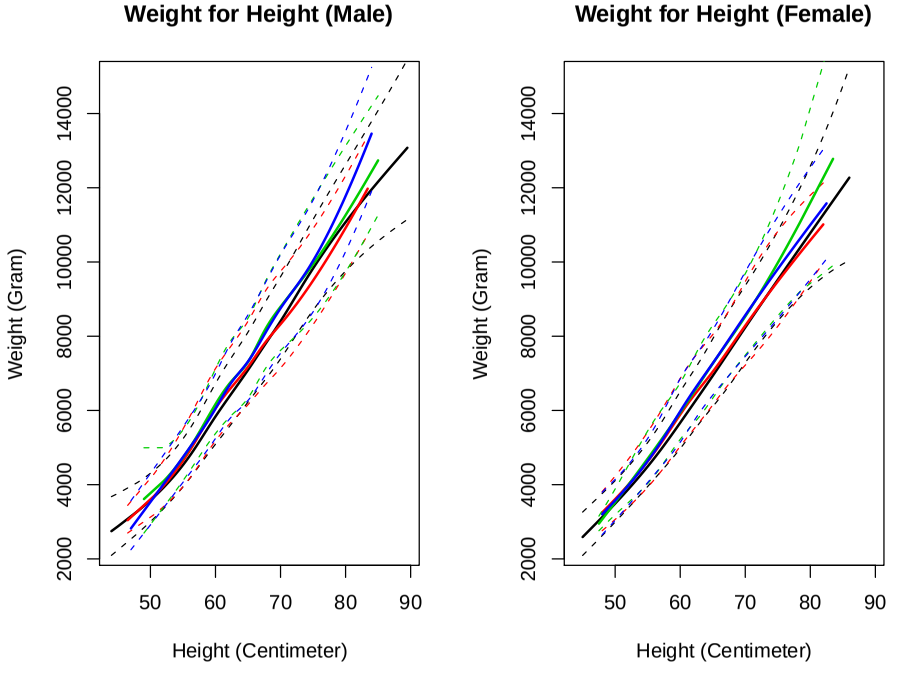

Figure 6.5: Growth charts describing weight for height. In these charts the black line represents the Dutch group, the red line the Surinamese group, the green line the Turkish group, and the blue line the Moroccan group. The continuous line describes the mean and the dotted lines the 5% and 95% percentiles of the distribution of the measurements.

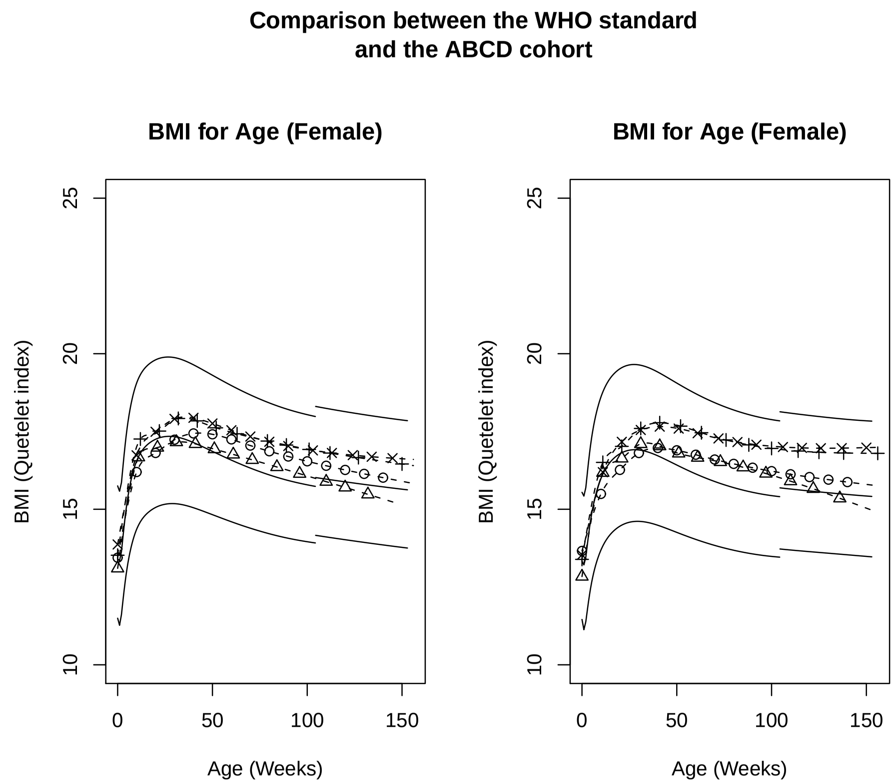

Figure 6.6: Growth charts describing the difference between the WHO growth standard and the children from the ABCD cohort in the BMI for age charts. The continuous lines describe the 5 , 50 , and 95 percentiles from the WHO growth standard. The dotted lines are the fitted curves from the ABCD cohort where ○ represents the Dutch group, △ the Surinamese group, + the Turkish group, and × the Moroccan group.

IV

Discussion

All growth patterns (height for age, weight for age, BMI for age, head circumference for age, and weight for height) were statistically significantly different between infants from mothers born in the Netherlands, the republic of Suriname, Turkey, and Morocco for both genders ($p < 0.0005$). With exception for BMI for age, the BIC was higher in all models with the added covariate country of origin of the mother for both genders. Therefore the BIC indicates that a correction for county of origin of the mother is especially warranted for the BMI for age growth charts, and less or not necessary for the other growth charts.

Quantifying the differences between migrant and immigrant children, small differences were found in the height for age and head circumference for age in both genders. Relatively large differences were found in weight for age, especially for girls from mothers born in Turkey and Morocco. These girls were one kilogram heavier at the age of 3 years compared to the girls from mothers born in the Netherlands. This difference was also reflected in BMI for age, with a smaller decline in BMI at 52 weeks compared to the infants from mothers born in the Netherlands. Children from mothers born in the republic of Suriname were born lighter than children from mothers born in the Netherlands and remained lighter during their childhood, but their growth patterns were comparable.

The observed differences in weight and BMI correspond with findings from previous studies. Fredriks et al. [46, 45, 150] reported that children of Moroccan and Turkish origin were heavier compared to the children of Dutch origin. These conclusions were based on the fourth Dutch Growth Study conducted in 1996 that included children from birth up to the age of 21 years. In that sample, the difference in growth rate was increasing with age with a peak at puberty. A study concerning overweight and obesity prevalence in children between 3-16 years conducted by de Wilde et al. [151] also showed that the BMI of children of Turkish and Moroccan origin was higher than the BMI of children from Dutch origin. Our study only included children from 0-3 years but also showed an increase of difference with age between the Moroccan and Turkish groups compared to the Dutch group.

The observed weight differences of infants from mothers born in Turkey and Morocco compared to the infants from mothers born in the Netherlands were higher for girls. This gender difference was also found by Fredriks et al. [46, 45], who concluded that girls of Moroccan origin were heavier for their height and had a higher BMI compared to girls of Dutch origin. They did not find large differences

in the BMI for age and weight for height charts between boys of Moroccan and Dutch origin. For infants of Turkish orgin the difference between weight was observed from the age of four weeks and onwards, which led to a difference of +0.3 kg in boys and +0.5 kg in girls at the age of 60 weeks.

Weight gain in infants is determined by many factors, making individual determinants difficult to assess. The observed differences in weight gain are likely to be caused by a combination of lifestyle, genetic, and environmental determinants. One of the main environmental factors is nutrition. Energy intake is a good predictor for weight gain during infancy and even during childhood and is largely influenced by the duration and type of nutrition offered (breastfeeding, bottle-feeding, or both) and the age at which complementary feeding is started [152, 153, 154]. Bulk-Bunschoten et al. compared the feeding habits of mothers of Dutch, Turkish, and Moroccan origin in the Netherlands and concluded that mothers of Moroccan and Turkish origin were more likely to give their child both breastfeeding and bottle-feeding. Mothers of Dutch origin had a higher rate of giving either exclusively breastfeeding or exclusively bottle feeding. Solid food was rarely given before the age of five months (ranging from 1.2% at three months and 1.9% at four months weeks of age in all groups) [155].

Unfortunately the registered information on feeding patterns in the current ABCD dataset was not detailed enough to test whether specific nutritional patterns could explain the differences in weight. Only the feeding type at birth (breastfeeding and/or bottle-feeding) was included and revealed that in all groups exclusively breastfeeding was the preferred nutrition given to infants at birth (mother born in the Netherlands: 2,565 (84%), republic of Suriname: 166 (76%), Turkey: 188 (95%), and Morocco: 305 (92%)). Since further information was not available, we assumed that the reference growth charts were based upon predominantly breastfed infants.

Other important factors explaining weight differences are the characteristics and lifestyle of the mother. In particular, maternal pre-pregnancy obesity is an important factor identified to predict childhood obesity [156]. Maternal obesity results in an abnormal in utero metabolic environment, which increases the risk of obesity for the child [157]. In the ABCD study there are differences in obesity rates between the comparison groups [139]. Compared to the Dutch group (3.7%) the first generation immigrant groups included a higher number of obese mothers (born in the republic of Suriname: 14.9%, Turkey: 10.4%, and Morocco: 12.9%). This may partly contribute to the higher weight of children from mothers of Turkish and Moroccan origin compared to the children from mothers of Dutch origin.

For children from mothers born in the republic of Suriname, the relation between maternal obesity and increased weight was not seen.

Other registered lifestyle factors that were heterogeneous distributed in the ABCD dataset between pregnant mothers born in the Netherlands and from first generation immigrant groups which might contribute to the differences found in weight gain of their children are an education shorter than five years (mother born in the Netherlands: 8.8%, republic of Suriname: 43.0%, Turkey: 62.6%, Morocco: 60.2%), being unemployed (mother born in the Netherlands: 17.5%, republic of Suriname: 46.8%, Turkey: 78.2%, Morocco: 75.9%), alcohol consumption (mother born in the Netherlands: 29.5% , republic of Suriname: 12.1%, Turkey: 0.7%, Morocco: 0.2%), suffering from a depression (mother born in the Netherlands: 6.9% , republic of Suriname: 20.9%, Turkey: 21.8%, Morocco: 15.7%), and smoking (mother born in the Netherlands: 10.2% , republic of Suriname: 12.4%, Turkey: 17.3%, Morocco: 2.5%) [139].

The WHO growth charts were based on growth measurements from children from six different countries. Potential environmental, lifestyle, and economic constraints on growth were prevented by a set of inclusion criteria for the mother and child. A child was only included when the mother was prepared to follow feeding recommendations and therefore the charts were based on breastfed infants. Also smoking before and after delivery was prohibited and a certain social economic status of the parents was required [158]. Similarly to the WHO growth charts, small differences were found for the development of height between children from mothers with different countries of origin (figure 6.1 and tables 6.1, 6.2) [143].

In this study a complete set of growth parameters was evaluated, based upon data from a large number of measurements. However, most of the measurements were taken before the children reached the age of two, resulting in a low density of measurements after this point (table 6.1). This problem was nevertheless solved by the LMST method since it introduced structure and was considered to be relatively stable and fairly accurate in regions with less data.

Differences in growth patterns increased after 2 years of age in all reference charts, which could still be the result of the decreasing number of measurements despite the structure introduced by the LMST method. However, in the weight for age charts differences had already occurred at 30 weeks of age, which was estimated with a large number of measurements. In addition the results could be influenced by the multiple measurements for each child. The models did not correct for this characteristic. Not dealing with repeated measures may have led to too small standard errors and too low -values, but with the current number of measurements

this overestimation may be ignored. Mixed effect models and non-parametric quantile regression models were also created, but both modeling techniques (given height of age for both genders) gave worse fits to the data than the models created with the LMST method (data not shown).

The definition of immigrant from the Dutch governmental statistics office did not confound our results; including second generation mothers in the Dutch group was the best decision since the growth charts of their children were somewhat more similar to the Dutch group than those of the immigrant groups. Unfortunately the number of children having a second generation mother was too small to investigate this phenomenon thoroughly (mothers categorized as second generation Surinamese: 59, second generation Turkish: 34, second generation Moroccan: 34).

The Surinamese group consisted of mothers from both Creole and Hindustan origin creating a mixed group. From both these groups too few measurements were available to examine them individually, but in the literature, however, Creole and Hindustan individuals are often grouped as Surinamese [159].

Our study shows that in the Netherlands separate reference curves for native Dutch children and children from immigrant groups fit the data of these groups better than one general curve. Especially the weight for age and BMI for age curves from children with mothers born in Turkey and Morocco were substantially different from the children with mothers born in the Netherlands. This difference could be a reflection of a complex mechanism of constitutional and environmental factors. Further investigation of the role of infant feeding patterns and other determinants in explaining these differences is needed.