Exclusive breastfeeding duration and cardiorespiratory fitness in children and adolescents

Idaoia Labayen, Jonatan R Ruiz, Francisco B Ortega, Helle M Loit, Jaanus Harro, Inga Villa, Toomas Veidebaum, and Michael Sjostrom

ABSTRACT

Background: Breastfeeding has been associated with a protective effect against cardiovascular disease. Higher cardiorespiratory fitness during childhood is associated with healthier cardiovascular profile later in life.

Objectives: The objective was to examine the association of exclusive breastfeeding duration with fitness in children and adolescents and to test the role of body composition and sociodemographic factors in this relation.

Design: At the time of the study, exclusive breastfeeding duration was reported by mothers and grouped into 4 categories: exclusively formula fed or breastfed for <3, 3–6, or >6 mo. Fitness was determined by a maximal cycle-ergometer test in 1025 children (aged 9.5 ± 0.4 y) and in 971 adolescents (aged 15.5 ± 0.5 y) from Estonia and Sweden.

Results: Longer duration of breastfeeding was associated with higher fitness regardless of confounders (+5.1% L/min; country, sex, age, pubertal status, and BMI (adjusted \( P < 0.001 \)) or fat mass and fat-free mass (FFM) (+3.3%; adjusted \( P < 0.001 \)). Further adjustment for birth weight, physical activity, and maternal educational level did not change the results (\( P = 0.001 \)). The results were consistent in children and adolescents with low (\( P < 0.001 \)) or high (\( P = 0.013 \)) FFM, in nonoverweight (\( P < 0.001 \)) or overweight (\( P = 0.002 \)) children and adolescents, in offspring of nonoverweight (\( P < 0.001 \)) or overweight (\( P = 0.003 \)) mothers, in mothers with a low (\( P = 0.004 \)) or high (\( P < 0.001 \)) educational level, and in participants born within upper (\( P = 0.001 \)), middle (\( P = 0.017 \)), or lower (\( P = 0.007 \)) tertiles of birth weight.

Conclusions: Longer exclusive breastfeeding has a beneficial effect on cardiorespiratory fitness in children and adolescents. Because early infant-feeding patterns are potentially modifiable, a better understanding of the possible programming effect of exclusive breastfeeding on cardiorespiratory fitness is of public health interest.

INTRODUCTION

Cardiorespiratory fitness (hereinafter called fitness) is a health marker across the life span and is one of the strongest predictors of all-cause of mortality in healthy and unhealthy individuals (1). Children and adolescents with a higher fitness level have a healthier cardiovascular profile at these ages and later in life (2–4). Indeed, high fitness attenuates the detrimental effect of excessive adiposity on cardiovascular health (5) and on the risk of becoming overweight (6).

There is compelling evidence that nutritional factors that act in critical time windows in early life may have long-term consequences for cardiovascular health and related morbidities later in life (7). Early nutritional factors include those that act during infancy, such as breast- or bottle-feeding (8). It has been reported that breastfeeding could exert a protective effect against CVD (4) and obesity development later in life, but the evidence is inconsistent (9–13). Recent systematic reviews have highlighted the need for further research, with relevant confounders influencing both breastfeeding duration and health outcomes controlled for (12, 14, 15).

Fitness is influenced by genetic, biological, and lifestyle factors. It has been suggested that genetic heritability of fitness is ~50% (16). Biological factors such as sex, age, pubertal status, growth, or maternal BMI (17) are also important predictors of fitness. Lifestyle factors also play an important role in explaining the remaining variance in fitness (2, 18, 19). Little is known, however, about the role of early feeding patterns on fitness.

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4 Abbreviations used: CVD, cardiovascular disease; FFM, fat-free mass; FM, fat mass; SES, socioeconomic status; VO\(_2_{max}\), maximal oxygen uptake.

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however, about the influence of the infant-feeding method and breastfeeding duration on fitness. Two previous studies reported a lack of association between breastfeeding duration and fitness during childhood (20) and adolescence (21), and only one (21) mentioned the influence of exclusive breastfeeding on fitness in a smaller study subsample.

The present study aimed to extend the current scant evidence on the developmental origins of fitness by examining the associations of exclusive breastfeeding with fitness assessed in a large cohort of children (aged 9–10 y) and adolescents (aged 15–16 y). We also investigated if 1) the breastfeeding-fitness association was mediated by differences in body size and composition and 2) whether the breastfeeding-fitness association was independent of several variables potentially related to duration of breastfeeding and/or fitness, such as objectively measured physical activity, birth weight, maternal weight status, and sociodemographic characteristics.

SUBJECTS AND METHODS

Study participants

The children and adolescents were participants in the Estonian (n = 966) and Swedish (n = 1030) part of the European Youth Heart Study, a multicenter study in children (aged 9.5 ± 0.4 y) and adolescents (aged 15.5 ± 0.5 y). The European Youth Heart Study is a school-based, cross-sectional study designed to examine the interactions between personal, environmental, and lifestyle influences on risk factors for future CVD. Study design, selection criteria, and sample calculations were reported elsewhere (22). Briefly, a total of 2312 children (n = 1144) and adolescents (n = 1168) were recruited between September 1998 and May 1999. In Estonia (n = 1176), the sampling area was the city of Tartu and its surrounding rural area. In Sweden (n = 1136), 8 municipalities were chosen for data collection (Botkyrka, Haninge, Huddinge, Nynäshamn, Salem, Södertälje, Tireso, and Örebro). The study protocol was performed in accordance with the ethical standards laid down in the 1961 Declaration of Helsinki (as revised in 2000) and approved by the Research Ethics Committees of the University of Tartu (no. 49/30–199), Örebro County Council (no. 690/98), and Huddinge University Hospital (no. 474/98). Children and adolescents gave verbal assent after procedures were explained, and one parent or legal guardian provided written informed consent. For the purpose of this study, a total of 1025 children and 971 adolescents with complete data on infant-feeding method and fitness were included in the present study (86.3% of the original study sample). Subjects were apparently healthy; had no contra-indications to any of the study procedures, including the maximal cycle-ergometer test; and were not taking medication that might influence the results. The final sample did not differ in the main characteristics (ie, breastfeeding duration, BMI, or fitness) from the original sample (all P > 0.1).

Physical examination

Height and weight were measured by using standardized procedures, and BMI was calculated. Overweight and obesity status in children and adolescents was defined following the International Obesity Task Force recommendations for sex- and age-adjusted BMI cutoffs (23). Skinfold thickness was measured with a harpenden caliper (Baty International) at the biceps, triceps, subscapular, suprailiaca, and triceps surae areas on the left side of the body according to the criteria described by Slaughter et al (24). All measurements were taken twice and in rotation, and the mean value was calculated. If the difference between the measurements was >2 mm, a third measurement was taken and the 2 closest measurements were averaged. Body fat percentage was calculated using Slaughter’s equations, which showed the best agreement with total body fat percentage measured by dual-energy X-ray absorptiometry in the adolescent population (25). FFM (kg) was derived by subtracting FM from total body weight. Pubertal status was assessed by direct observation by a trained researcher and according to Tanner and Whitehouse (Tanner stages from I to V) (26).

Infant-feeding data

Data on duration of breastfeeding were collected from parental recall by using a questionnaire completed at home. Mothers were asked to respond to 2 questions concerning breastfeeding at the time of the examination of the children, but they were not aware of the following particular research questions:

1) Was your child fed completely on breast milk for any length of time—that is, without complementary formula feeds? (Categories provided for response were yes or no.)
2) For how long was your child breastfed? (Categories provided for response were <1 mo, >1–3 mo, >3–6 mo, and >6 mo.)

The duration of exclusive breastfeeding was defined according to the definition provided by WHO as no liquid or solid nutrition other than breast milk.

We categorized the breastfeeding variable according to the presence and the duration of exclusive breastfeeding, taking into account the answers to the 2 above-mentioned questions. Likewise, those cases for whom the answer to the first question (Was your child fed completely on breast milk for any length of time—that is, without complementary bottle feeds?) was “yes” were considered as “exclusively breastfed”; thereafter, we categorized them according to the duration of breastfeeding, taking into account the answer to the second question (For how long was your child breastfed?). Those cases for whom the answer to the first question was “no” and who did not answer the second question were considered as “exclusively formula-fed participants.” Finally, those mothers who answered “no” to question 1 and then responded to question 2 with any period of time were classified as “mixed-diet” subjects.

For the purpose of this study, a total of 19 participants who had received a mixed diet as infants (breastfeeding and formula-feeding) were excluded from the analyses. The original breastfeeding duration categories were recoded and stratified into 4 categories: exclusively formula-fed and <3, 3–6, and >6 mo of exclusive breastfeeding.

Cardiorespiratory fitness

Fitness was determined by a maximal cycle-ergometer test (27). The work rate was preprogrammed on a computerized cycle ergometer (Monark 829E Ergomedic; Monark Exercise AB) to
increase every third minute until exhaustion. Heart rate was registered continuously by telemetry (Polar Sport Tester). The criteria for exhaustion were a heart rate of ≥185 beats/min and a subjective judgment by the test leader that the children and adolescents could no longer keep up, even after vocal encouragement. The power output [watts (W)] was calculated as \( W_1 + (W_2 \times t/180) \), where \( W_1 \) is the work rate at the last fully completed stage, \( W_2 \) is the work rate increment at the final incomplete stage, and \( t \) is time in seconds at the final incomplete stage. In the present study, we chose to use \( \text{VO}_2 \max \) in absolute terms (L/min), and to include BMI or FM and FFM as covariates in the models, to examine the possible confounding/mediating effect of body size and body composition.

Assessment of potential confounding factors

Several variables potentially related to duration of breastfeeding or to fitness (eg, birth weight), SES, maternal BMI, and physical activity were considered as potential confounders (17, 28–32).

Data on birth weight were obtained from parental recall by using a questionnaire, and children’s and adolescents’ smoking habits were self-reported. The validity of parent-reported birth weight data was verified in a randomly selected subset of the study sample (49%) by using available measured birth weights from hospital records (33). The results showed no significant differences in birth weight collected from parental recall and those obtained from hospital records.

SES was assessed via questionnaire and defined by maternal educational status, coded as 0 (below university education) and 1 (university education). SES data were available for 98.8% of children (98.9% of girls and 98.7% of boys) and for 98.6% of adolescents (98.8% of females and 98.3% of males).

Mothers reported their age, weight, and height; we calculated their BMI. The mother’s BMI was considered as a potential confounder because this is related to her child’s size at birth and the child’s later fitness and body size and composition (17). Maternal BMI was available for 97.0% of children (96.4% of girls and 97.6% of boys) and for 96.5% of adolescents (96.7% of females and 96.2% of males). Mothers with a BMI (in kg/m²) ≥25 were categorized as being overweight/obese (hereafter called overweight), whereas those with a BMI <25 were classified as nonobese according to international standards (34). Physical activity was measured over 4 consecutive days (2 weekdays and ≥1 weekend day) with an activity monitor (MTI model WAM 7164; Manufacturing Technology Inc) attached to the right hip (35). Total physical activity was defined as total activity counts divided by monitor wear time and expressed as counts per minute (counts/min). Physical activity was available for 70.4% of children (69.8% of girls and 71.1% of boys) and for 59.7% of adolescents (64.4% of females and 55.0% of males).

Statistical methods

Statistical analyses were performed by using SPSS software version 17.0 (SPSS Inc), and the level of significance was set at 0.05. Data are presented as means and SDs unless otherwise stated. Variables with skewed distribution—ie, BMI, FM, FFM, and physical activity—were log-transformed to obtain a more symmetric distribution.

Differences in pubertal status, percentages of males compared with females, and percentages of children compared with adolescents among exclusive-breastfeeding categories (exclusively formula-fed or breastfed for <3, 3–6, or >6 mo), as well as overweight and obesity prevalence, were analyzed by chi-square test; differences in age, BMI, FM, FFM, and birth weight between breastfeeding categories were analyzed by 1-factor ANOVA. We explored the differences in fitness between the 4 categories of exclusive breastfeeding by 1-factor ANCOVA in 3 separate models. Model 1 included the dependent variable (fitness), the fixed factor (breastfeeding categories), and country, age, sex, and pubertal status as covariates. In model 2, BMI was included as a covariate. Model 3 included model 2 covariates but with FM and FFM as covariates instead of BMI. In model 4, birth weight, SES, and maternal BMI were entered as covariates because these variables might confound the relations in that they are related to the exposure and are likely to be associated with fitness (17, 28–30). In model 5, analyses were additionally controlled for physical activity. All of the analyses were repeated, stratifying by country, sex, or age group (children and adolescents). Moreover, we repeated all of the analyses with fitness levels in relative terms (ie, normalized by body weight; mL · kg⁻¹ · min⁻¹). Similarly, we tested the influence of breastfeeding (exclusively formula-fed compared with ever been breastfed) on fitness by ANCOVA. The association between duration of breastfeeding and fitness was additionally analyzed separately for adolescents with high or low FFM (above or below the sex- and age group–specific median).

Finally, we studied the influence of exclusive breastfeeding across weight status categories (nonoverweight compared with overweight), SES categories (low SES compared with high SES), maternal weight status categories (nonoverweight compared with overweight), and birth weight categories (lower, middle, and upper birth weight tertiles). Birth weight was categorized into 3 sex-specific tertiles as follows: <3220, 3220–3650, and >3650 g for low, middle, and upper tertiles, respectively, in girls; <3390, 3390–3850, and >3850 g for low, middle, and upper tertiles, respectively, in boys.

RESULTS

Breastfeeding was more frequent (P < 0.001) and of longer duration (P = 0.002) in Swedish than in Estonian children and adolescents (Table 1). Fitness levels were higher in Swedish

<table>
<thead>
<tr>
<th>TABLE 1</th>
</tr>
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<tbody>
<tr>
<td>Patterns of exclusive breastfeeding duration in Swedish and Estonian children and adolescents</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Duration of breastfeeding</th>
<th>Children (n = 508)</th>
<th>Adolescents (n = 458)</th>
<th>Children (n = 517)</th>
<th>Adolescents (n = 513)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exclusively formula-fed</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
</tr>
<tr>
<td>Breastfed</td>
<td>16.7</td>
<td>21.7</td>
<td>12.0</td>
<td>13.0</td>
</tr>
<tr>
<td>&lt;3 mo</td>
<td>60.2</td>
<td>50.2</td>
<td>31.1</td>
<td>36.0</td>
</tr>
<tr>
<td>3–6 mo</td>
<td>13.9</td>
<td>18.4</td>
<td>38.9</td>
<td>32.7</td>
</tr>
<tr>
<td>&gt;6 mo</td>
<td>9.2</td>
<td>9.7</td>
<td>18.0</td>
<td>18.3</td>
</tr>
</tbody>
</table>

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EXCLUSIVE BREASTFEEDING AND FITNESS IN CHILDREN AND ADOLESCENTS

TABLE 2
Descriptive characteristics of children and adolescents among infant-feeding categories

<table>
<thead>
<tr>
<th>Infant-feeding method</th>
<th>Exclusively formula-fed (n = 317)</th>
<th>Exclusively breastfeeding &lt;3 mo (n = 877)</th>
<th>Exclusively breastfeeding 3–6 mo (n = 521)</th>
<th>Exclusively breastfeeding &gt;6 mo (n = 281)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>12.7 ± 3.02</td>
<td>12.3 ± 3.0</td>
<td>12.5 ± 3.0</td>
<td>12.5 ± 3.0</td>
<td>0.249</td>
</tr>
<tr>
<td>Children (%)</td>
<td>46.3</td>
<td>51.9</td>
<td>51.2</td>
<td>50.6</td>
<td>0.106</td>
</tr>
<tr>
<td>Puberty stage (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage I</td>
<td>34.1</td>
<td>41.9</td>
<td>41.2</td>
<td>41.6</td>
<td>0.209</td>
</tr>
<tr>
<td>Stage II</td>
<td>11.6</td>
<td>12.4</td>
<td>11.9</td>
<td>10.1</td>
<td></td>
</tr>
<tr>
<td>Stage III</td>
<td>7.3</td>
<td>1.1</td>
<td>3.7</td>
<td>7.3</td>
<td></td>
</tr>
<tr>
<td>Stage IV</td>
<td>20.4</td>
<td>17.5</td>
<td>14.8</td>
<td>13.6</td>
<td></td>
</tr>
<tr>
<td>Stage V</td>
<td>26.5</td>
<td>23.4</td>
<td>28.4</td>
<td>27.3</td>
<td></td>
</tr>
<tr>
<td>Females (%)</td>
<td>58.9</td>
<td>52.7</td>
<td>53.9</td>
<td>50.2</td>
<td>0.186</td>
</tr>
<tr>
<td>Birth weight (g)</td>
<td>3427 ± 690</td>
<td>3503 ± 572</td>
<td>3547 ± 538</td>
<td>3532 ± 633</td>
<td>0.055</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>154.7 ± 16.6</td>
<td>152.9 ± 17.3</td>
<td>153.8 ± 17.4</td>
<td>154.5 ± 18.0</td>
<td>0.256</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>19.1 ± 3.4</td>
<td>18.6 ± 3.0</td>
<td>18.9 ± 3.1</td>
<td>19.0 ± 3.0</td>
<td>0.093</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>9.1 ± 6.3</td>
<td>8.1 ± 5.1</td>
<td>8.3 ± 5.1</td>
<td>8.4 ± 4.8</td>
<td>0.057</td>
</tr>
<tr>
<td>Fat-free mass (kg)</td>
<td>57.0 ± 108.3</td>
<td>54.1 ± 101.6</td>
<td>67.4 ± 132.8</td>
<td>74.5 ± 148.5</td>
<td>0.212</td>
</tr>
<tr>
<td>Overweight/obese (%)</td>
<td>22.6</td>
<td>20.1</td>
<td>21.3</td>
<td>19.7</td>
<td>0.613</td>
</tr>
<tr>
<td>Smoker (%)</td>
<td>13.3</td>
<td>13.5</td>
<td>12.9</td>
<td>10.8</td>
<td>0.700</td>
</tr>
<tr>
<td>Maternal educational level below university (%)</td>
<td>74.1</td>
<td>72.6</td>
<td>62.1</td>
<td>52.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Maternal age at childbirth (y)</td>
<td>28.7 ± 5.1</td>
<td>27.9 ± 5.3</td>
<td>28.9 ± 4.8</td>
<td>29.1 ± 5.2</td>
<td>0.060</td>
</tr>
<tr>
<td>Maternal BMI (kg/m²)</td>
<td>24.9 ± 5.0</td>
<td>23.9 ± 4.1</td>
<td>23.9 ± 3.8</td>
<td>23.6 ± 3.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fitness (mL · kg⁻¹ · min⁻¹)</td>
<td>39.8 ± 7.8</td>
<td>41.0 ± 7.5</td>
<td>41.9 ± 7.9</td>
<td>41.5 ± 7.7</td>
<td>0.001</td>
</tr>
<tr>
<td>Fitness (VO₂ max, L/min)</td>
<td>1.86 ± 0.73</td>
<td>1.84 ± 0.77</td>
<td>1.96 ± 0.86</td>
<td>1.98 ± 0.88</td>
<td>0.014</td>
</tr>
<tr>
<td>Physical activity (counts/min)</td>
<td>601 ± 211</td>
<td>640 ± 266</td>
<td>629 ± 237</td>
<td>633 ± 251</td>
<td>0.319</td>
</tr>
</tbody>
</table>

1 Values were analyzed by using 1-factor ANOVA. VO₂ max, maximal oxygen uptake.
2 Mean ± SD (all such values).
3 Analysis was performed by using log-transformed data, but nontransformed data are presented in the table.

(2.00 ± 0.87 L/min) than in Estonian (1.78 ± 0.74 L/min) children and adolescents (P < 0.001). We did not observe any significant differences in the distribution of age groups (children/adolescents), sex (girls/boys), or pubertal status percentages between the breastfeeding duration categories (Table 2). Similarly, the percentage of overweight children and adolescents and those who smoked, as well as level of physical activity did not differ across breastfeeding categories. However, longer breastfeeding duration tended to be associated with lower BMI and with higher birth weight (P < 0.1), higher SES (P < 0.001), and lower maternal BMI (P < 0.001) (Table 2). Fitness, expressed either in absolute terms (L/min) or normalized for body weight (mL · · kg⁻¹ · min⁻¹), increased with exclusive duration of breastfeeding (P < 0.05). Maternal age at childbirth tended to associate with duration of breastfeeding (P < 0.1), yet this association did not show a clear direction (Table 2).

Role of body size and composition on the relation between breastfeeding and fitness

We observed that those children and adolescents who had breastfed as infants showed significantly higher fitness levels (1.89 ± 0.01 L/min) than those who were exclusively formula-fed (1.79 ± 0.02 L/min) (adjusted for country, sex, age, pubertal status, and BMI; P < 0.001) (Figure 1, models 1 and 2). The outcome persisted when the analysis was controlled for FM and FFM instead of BMI (Figure 1, model 3). Moreover, the results did not substantially differ when fitness levels were normalized by body weight (40.0 ± 0.4 compared with 41.2 ± 0.2 mL · kg⁻¹ · min⁻¹) for exclusively formula-fed and exclusively breastfed, respectively (adjusted for country, sex, age, and pubertal status; P = 0.004).

Longer duration of breastfeeding was significantly associated with higher fitness (P < 0.001) regardless of confounders...
(country, sex, age, and pubertal status) (Figure 2, model 1), and this association remained significant after further adjustment for BMI (Figure 2, model 2) and when FM and FFM were entered into the model instead of BMI (Figure 2, model 3). The outcome did not substantially change when fitness levels were normalized by body weight (40.0 ± 0.4, 40.9 ± 0.2, 41.8 ± 0.3, and 41.1 ± 0.4 mL · kg⁻¹ · min⁻¹ for exclusively formula-fed and breastfed for <3, 3–6, and >6 mo, respectively; adjusted for country, sex, age, and pubertal status; \( P < 0.001 \)).

We also observed that fitness levels were significantly higher in those children and adolescents who had breastfed for \( \geq 3 \) mo, compared with those who were breastfed for a shorter duration (Figure 2). Indeed, there were no significant differences in fitness levels between participants who had exclusively breastfed for \( \leq 3 \) or \( \geq 6 \) mo (adjusted for confounders + BMI, \( P = 0.756 \), and for confounders + FM and FFM, \( P = 0.563 \)).

Moreover, the association between breastfeeding duration and fitness was significant in children and adolescents with higher or lower FFM (Figure 3A) and in nonoverweight or overweight children and adolescents (Figure 3B).

The outcome did not substantially change when the results were examined separately by sex or country (data not shown).

Role of birth weight, SES, maternal BMI, and physical activity on the relation between breastfeeding and fitness

Fitness levels were higher in those children and adolescents who had breastfed in infancy (1.89 ± 0.01 L/min) as compared with those who had been formula-fed (1.81 ± 0.02 L/min), regardless of age, sex, pubertal status, BMI, birth weight, maternal BMI, and SES (Figure 1, model 4). The outcome persisted after further adjustment for physical activity (Figure 1, model 5).

Longer breastfeeding duration was significantly associated with higher fitness level independently of the above-mentioned

FIGURE 2. Adjusted mean (±SE) cardiorespiratory fitness (\( \text{\_VO}_2 \text{max} \), L/min) in children and adolescents by duration of exclusive breastfeeding [ie, never (formula-fed) or exclusively breastfed for <3, 3–6, or >6 mo]. Data were analyzed by 1-factor ANCOVA. Model 1: adjusted for country, age, sex, and pubertal status; model 2: adjusted as for model 1 and additionally adjusted for BMI; model 3: adjusted for country, age, sex, pubertal status, fat mass, and fat-free mass; model 4: adjusted as for model 2 and additionally adjusted for birth weight and maternal BMI and educational level; model 5: adjusted as for model 4 and additionally adjusted for physical activity. ***Significantly different from never-breastfed: * \( P < 0.05 \), ** \( P < 0.001 \). \( \text{\_VO}_2 \text{max} \), maximal oxygen uptake.

FIGURE 3. Adjusted mean (±SE) cardiorespiratory fitness (\( \text{\_VO}_2 \text{max} \), L/min) in children and adolescents by duration of exclusive breastfeeding [ie, never (formula-fed) or exclusively breastfed for <3, 3–6, or >6 mo] according to FFM (A) and weight status (B). Low and high groups of FFM were considered as below or above the sex- and age group–specific median, respectively. Data were analyzed by 1-factor ANCOVA. The set of confounders was country, sex, age, pubertal status, and body mass. \( P \)-interaction between exclusive breastfeeding duration and low or high FFM, \( < 0.001 \); \( P \)-interaction between exclusive breastfeeding duration and weight status, \( < 0.001 \). FFM, fat-free mass; \( \text{\_VO}_2 \text{max} \), maximal oxygen uptake.
confounders (country, sex, age, pubertal status, and BMI) and independently of birth weight, maternal BMI, and SES (Figure 2, model 4). Furthermore, the result was not altered after further adjustment for physical activity (Figure 2, model 5; 1.77 ± 0.02, 1.81 ± 0.01, 1.88 ± 0.02, and 1.86 ± 0.02 L/min for exclusively formula-fed and breastfed for <3 mo, 3–6 mo, and >6 mo, respectively; adjusted $P = 0.001$). Additional adjustment for maternal age at the child’s birth did not substantially change the results (data not shown).

Moreover, the relation between exclusive breastfeeding duration was consistent in children and adolescents born in the lower, middle, or upper birth weight tertiles (Figure 4A), in offspring of mothers who were overweight or nonoverweight (Figure 4B), and in children and adolescents with either low or high SES (Figure 4C).

**DISCUSSION**

In the present study, we found that longer exclusive breastfeeding duration was associated with higher cardiorespiratory fitness in a relatively large sample of Estonian and Swedish children and adolescents. This relation was consistent independently of children and adolescents’ body size and composition and regardless of physical activity and sociodemographic factors that might influence this association.

To the best of our knowledge, there are only 2 studies investigating the influence of breastfeeding on fitness (20, 21), and only one (21) mentioned the influence of exclusive breastfeeding in a smaller study subsample. Lawlor et al (20) reported a lack of association between any breastfeeding duration and fitness assessed by biking test during childhood. The inclusion of mixed-fed individuals in the comparisons may dilute any potential advantageous effect of breastfeeding. In the study by Artero et al (21), a longer breastfeeding duration was associated with better performance in the standing long jump test in adolescents, but there was no significant relation between breastfeeding and fitness (assessed by the 20-m shuttle run test) in adolescents. The type of exercise test used will influence the outcome; thus, the shuttle run test is more influenced by body weight than is the cycle-ergometer test.

Because a purpose of the present study was to explore the role of body size and composition on the association between breastfeeding and fitness, to express fitness in relative terms (ie, normalized by body weight or FFM) would be problematic and would lead to a complicated interpretation of the results when body size and composition variables are further adjusted for. Likewise, because fitness (in L/min) is higher in larger individuals due to differences in weight status and in FFM, we additionally analyzed the relation between breastfeeding and fitness separately in overweight and nonoverweight children and adolescents and in children and adolescents with low and high FFM. As expected, fitness levels were higher in overweight than in nonoverweight children and adolescents and in participants with high FFM than in those with low FFM. Interestingly, however, there were strong associations between the duration of exclusive breastfeeding and fitness in nonoverweight and overweight children and adolescents and in low- and high-FFM groups.

One important issue in studies examining the influence of infant feeding on CVD risk later in life (ie, cardiorespiratory fitness) is that breastfeeding is associated with less obesogenic maternal characteristics, such as higher educational level (32) or lower maternal BMI (17). Similarly, higher birth weight is related to longer duration of breastfeeding, higher fitness, and higher FFM (20, 28, 29, 36); and physical activity level is an important lifestyle determinant of fitness (2). Therefore, it was not surprising to find that fitness was higher in individuals born within the upper tertile of birth weight than in the other tertiles and in individuals with higher SES than in those with low SES. Also, the higher fitness levels observed in individuals with overweight mothers than in those with nonoverweight mothers is related to the established relation between maternal and offspring BMI and weight status. Of note in our report, the relation between

**FIGURE 4.** Adjusted mean (±SE) cardiorespiratory fitness (VO$_2$ max, L/min) in children and adolescents by duration of exclusive breastfeeding [ie, formula-fed or exclusively breastfed for <3, 3–6, or >6 mo] according to BW categories (A), maternal weight status (B), and maternal SES (C). BW was categorized into 3 sex-specific tertiles. Low- and high-SES groups were considered as less than university education and university education, founders was country, sex, age, pubertal status, and body mass. $P$-interaction between exclusive breastfeeding duration and BW tertiles = 0.001; $P$-interaction between exclusive breastfeeding duration and maternal weight status, <0.001; $P$-interaction between exclusive breastfeeding duration and maternal SES = 0.005. BW, birth weight; SES, socioeconomic status; VO$_2$ max, maximal oxygen uptake.
exclusive breastfeeding and fitness was independent of birth weight, maternal BMI, maternal educational level, and objectively measured physical activity. Furthermore, this relation was consistent across birth weight categories, SES categories, and maternal weight status categories.

Our findings suggest that early infant feeding method affects an important health marker associated with CVD later in life. Our results, together with previous epidemiologic and experimental studies suggest that exclusive breastfeeding in infancy during ≥3 mo has beneficial effects on cardiovascular health later in life. We found that being exclusively breastfed (ever breastfed) was associated with an increase of ~5.3% in fitness levels in absolute terms (VO₂ max, L/min) or of ~3% when fitness was normalized by body weight (mL ⋅ kg⁻¹ ⋅ min⁻¹). The effect size of the association was relatively small. This is expected because a large number of genetic and environmental factors influence fitness, being breastfeeding, one more single factor contributing to the total variance explained. For example, in our regression model, sex (49.7% of variability), age (19.3% of variability), and BMI (5.3% of variability) explained most of the variability in fitness levels, whereas meeting the recommendation of moderate to vigorous physical activity was associated with an increase of 14.9% of variability in fitness levels. If this association is causal and continues into adulthood, it is possible that an effect of early nutrition on fitness mediates some of the established inverse associations between breastfeeding and later adverse health outcomes, in particular CVD outcomes.

Nevertheless, an obstacle to assigning causality is the lack of evidence in humans of any mechanism whereby breastfeeding could diminish CVD risk factors later in life. Several studies suggested that the nutritional programming of CVD risk can be regarded as a specific instance of programming of human aging (37). The presence of specific nutrients with health benefits in breast milk, such as long-chain PUFA, trophic substances, hormones, or specific nutrients, which are absent in formula milk, have been proposed as candidates for this nutritional programming (38, 39). However, the mechanism underlying the relation between breastfeeding and cardiovascular health remains speculative. Others proposed that sociobiological factors that influence both the mother’s decision to breastfeed and later cardiovascular risk could explain the associations (40).

Our study has several strengths such as the relatively large sample size with valid data on both exclusive breastfeeding duration and fitness in 86.3% of the original study sample and the availability of potential confounding factors. Moreover, the opportunity to examine the association of exclusive breastfeeding instead of any breastfeeding, in which the associations could be diluted, should be highlighted. However, several factors have to be acknowledged as potential limitations of the current report, as follows: maternal recall of breastfeeding 9 and 15 y later and the recording of the duration of breastfeeding; categorization of the duration of breastfeeding into 4 groups, instead of as a continuous variable in weeks; the lack of information on gestational age; maternal ethnicity; and finally, the lack of information on growth patterns of participants. On the other hand, because the mothers did not know the fitness level, or other cardiometabolic outcomes, of their offspring we cannot see any reason for an overestimation of breastfeeding duration.

In conclusion, we found that longer exclusive breastfeeding has a beneficial effect on cardiorespiratory fitness in children and adolescents. In the context of the developmental origins of health and disease these results suggest a role for breastfeeding in fitness. Because early infant-feeding patterns are potentially modifiable, a better understanding of the possible programming effect of breastfeeding on physical fitness is of public health interest. Nevertheless, these findings should be replicated in other studies with large samples and with long-term follow-up to determine their long-term importance.

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