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ARTICLE

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Nutrition during the early life cycle

Birth weight and breastfeeding are differentially associated with physical fitness components

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BACKGROUND/OBJECTIVES: The study purpose was to assess the impact of birth weight and breastfeeding duration on physical fitness components.
SUBJECTS/METHODS: Study participants were 985 adolescents boys and 1246 girls (12.5–17.5 years) participating in the HELENA study. Standardised physical fitness procedures included: cardio-respiratory fitness, flexibility, upper body muscular strength, and lower body explosive strength. Birth weight and breastfeeding duration were assessed by parents' questionnaire. Associations between neonatal data and physical fitness were investigated using linear mixed models.
RESULTS: Significant associations between body muscular strength, and breastfeeding duration were observed in the unadjusted analyses for boys. When adjusting for potential confounding factors (z-score body mass index, fat-free mass, fat mass), only lower body muscular strength, by standing broad jump-a proxy measure of muscular explosivity- was positively associated with breastfeeding duration. Furthermore, significant associations were observed between upper body muscular strength (by hand grip), —a proxy measure of muscular power—in boys as well as in girls.
CONCLUSIONS: Birth weight and breastfeeding duration have different effects on muscular strength components. The present results suggest that birth weight positively influences the development of muscular power, while breastfeeding duration positively influences muscular explosivity.

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INTRODUCTION

Physical fitness (PF) is a set of physical aptitudes consisting of several physical performance components, including cardio-respiratory fitness, flexibility, speed/agility, muscular strength, endurance and body composition [1, 2]. PF is generally defined as a state characterised by the human ability to carry out daily vigorous physical activities, demonstrating traits and capacities associated with low risk of premature development of diseases produced by lack of exercise (hypokinetic diseases) [3]. More generally, greater PF reflects better health and a lower risk of health problems [4]. PF is a powerful predictor of all-cause morbidity and mortality in adults [5, 6]. It is well accepted that PF is primarily influenced by three factors: genetic (heritability), lifestyle, and biological. Heritability of muscle strength is around 50–65% [7–9] and 47% for cardio-respiratory fitness [10]. Maintenance of a good PF is permitted by a healthy lifestyle, including as sufficient physical activity (PA) level [11]. Regarding biological factors, the generally accepted explanation comes from the Developmental Origins of Health and Disease theory [12, 13]. The preconceptual, prenatal, and/or early postnatal periods are especially crucial to individuals' later non-communicable disease incidence (i.e. diabetes, cardio-vascular diseases, cancers, chronic respiratory disease, neurodegenerative disorders) [14, 15].

PF components in adolescence have been widely assessed using well detailed and validated PF procedures such as FITNESSGRAM [16] and EUROFIT battery [17] and adapted for several European studies such as AVENA, EYHS and HELENA [18]. Several studies on adolescent PF have shown a positive association between bone health and upper and lower body strength [19] and cardiovascular health status [20]. Longitudinal studies on PF shown that low muscular fitness during adolescence persists into adulthood [21, 22] and a recent meta-analysis (included 30 studies) shown that low muscular fitness in adolescence was associated with high adiposity level

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and poor cardio-metabolic health [23]. Because muscular fitness is also a good predictor of disability in the elderly [24], a greater understanding of the programming effects of perinatal factors on muscular strength in adolescence is of public health interest. Previous perinatal factors studies have shown that breastfeeding is associated with lower limb muscular strength [25] and that birth weight is associated with upper limb muscular strength in children and adolescents [26]. However, the impacts of both birth weight and breastfeeding duration on PF using the same population-based sample have not been assessed. Our study purpose was to assess the associations between birth weight and breastfeeding duration on PF components among European adolescents.

SUBJECTS AND METHODS

Sample

Study data were derived from the Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA) study from ten cities in nine countries in northern (Ghent, Belgium; Lille, France; Dortmund, Germany; Stockholm, Sweden), central (Pecs, Hungary; Vienna, Austria), and southern (Athens, Greece; Rome, Italy; Zaragoza, Spain) Europe from 2006 to 2007, as previously described [27]. Briefly, HELENA was a multisite study designed to obtain reliable and comparable data from European adolescents aged 12.5–17.5 years about nutritional habits and patterns, body composition, and levels of PA and PF. Sampling procedure details, field team preparation and process, pilot study and data reliability were presented elsewhere [28]. The study was performed in accordance with the ethical guidelines of the Declaration of Helsinki, good clinical practice, and legislation concerning clinical research in each of the participating countries [29]. The protocol was approved by the appropriate independent ethics committee for each study centre [30]. Before beginning the study, its objectives, procedures and tests were carefully explained by the study physician to each participant and their parents/guardian. Written informed assent was obtained from the participant and consent from the parents (or guardian).

The number of adolescents to be studied was estimated at 3000 to analyse principal evaluation criteria (BMI) and 740 adolescents were considered enough to analyse secondary criteria [31]. The inclusion criteria's were: male and female subjects aged [12.5–17.5] years old, schooling in one of the participating classes, informed consent form signed by the parents and/or the legal guardian and exclusion criteria was subject which was participate simultaneously in another similar research [31].

A total of 3865 adolescents were enroled through their schools, which were randomly selected according to proportional cluster sampling accounting for age and socio-economic status [31]. The study was designed to assess breastfeeding duration and birth weight, two important perinatal factors contributing to PF. Consistent with this objective, because PF is impaired in premature children born small for gestational age, adolescents born at <35 weeks gestation ($n = 236$) were excluded from analyses [32, 33]. An additional 1076 participants with missing data were excluded (735 missing gestational duration, 341 missing PF data). In this context, 985 boys and 1246 girls were analysed.

Birth weight and breastfeeding duration

A parental questionnaire was developed to collect exclusive or not breastfeeding duration, gestational duration, and birth weight information [28]. Parents were specifically asked to recall this information based on health record booklets. Exclusive breastfeeding duration was reported in four categories: no breastfeeding, <3 months, ≥3 to <6 months, and ≥6 months [34]. The gestational duration was reported in three categories: <35 weeks, 35–40 weeks, and >40 weeks. The questionnaire was sent to parents before study inclusion and was collected at their adolescent's examination.

Anthropometrics

Weight was measured in underwear, with shoes removed, using an electronic scale (SECA® 861, SECA®, Birmingham, UK) to the nearest 0.1 kg. Height was measured with shoes removed using a telescopic height metre (SECA® 225) to the nearest 0.1 cm. Body mass index (BMI) was calculated by dividing body weight (kg) by height squared (m^2).

Physical fitness

The rationale for the selection of the fitness tests, their reliability in adolescents, and PF testing protocol details were published elsewhere [35–37].

Cardio-respiratory fitness (CRF) was assessed using the 20 m shuttle run test to reach maximal oxygen consumption (VO_2 max) [38]. The test was performed once. Participants were required to run between two lines spaced 20 m apart while keeping pace with pre-recorded audio signals. The initial speed was 8.5 km/h and was increased by 0.5 km/h per minute (1 min = 1 level). Participants were instructed to run in a straight line, to pivot on completing a shuttle, and to pace themselves in accordance with the audio signals. The test was finished when the participant stopped because of fatigue or failed to reach end lines concurrent with the audio signals twice consecutively. The last completed level or half-level at which the subject dropped out was recorded and used for the result of the test. CRF/VO_2 max data were expressed by the level number recorded at the shuttle run test.

Flexibility was assessed by the back-saver sit-and-reach test. The back-saver sit-and-reach was a part of the sit-and-reach test from FITNESSGRAM battery [16] adapted in back-saver sit-and-reach from EUROFIT battery [17]. Participants were required to sit in front of a standardised box and were instructed to push by bending their trunk and reach forward with one leg straight and the other bent at the knee. The test was performed once again with the opposite leg. The farthest position of the bar reached by each leg was scored in centimetres and the average of the distances reached by both legs was used in the analyses.

Speed/agility was assessed by the 4 × 10 m shuttle run test, an adapted test from the EUROFIT battery [17]. To perform this test, two parallel lines were drawn on the floor 10 m apart. Participants were required to run as fast as possible from the starting line to the other line and return to the starting line, crossing each line with both feet every time. This was performed twice, covering 40 m (4 × 10 m). Each time the participants crossed either line, they were instructed to pick up (the first time) or exchange (second and third times) a sponge that had been placed behind the lines. The stopwatch was stopped when the participant crossed the end line with one foot. The time taken to complete the test was recorded to the nearest tenth of a second.

Upper body muscular strength (UBMS) was first assessed by the handgrip test, using a hand dynamometer with adjustable grip (Hand Grip Digital Dynamometer TKK 5401 Grip D; Takei, Japan). In the standing position, the participant squeezed gradually and continuously for at least 2 s, performing the test with their right and left hands in turn, with their elbow in full extension [39, 40]. The grip span of the dynamometer was adjusted according to the participant's hand size using an equation specifically developed for adolescents [41]. The test was performed twice for each hand was recorded in kilograms. The maximum score from left and right hand was used to compute the average of hand grip data which was used in the analyses. A secondary UBMS assessment was the flexed arm hang test, for which participants hung from a bar for as long as possible, with their arms bent at 90°, palms forward, and chin over the bar's plane. The time spent in this position was recorded to the nearest tenth of a second.

Lower body explosive strength (LBES) was assessed using four tests: (i) For the standing broad (long) jump, the participant was required to jump as far as possible with feet together on a non-slip hard surface from a starting position. Swinging of the arms and bending of the knees were allowed. The data recorded were the longest distance in centimetres. For the following tests, a Bosco series of jump height maximal performance in centimetres was recorded using an infra-red platform Bosco systems (Ergo Jump PlusF Bosco systems Byomedic, Barcelona, Spain). (ii) For the squat jump, participants were required to perform a vertical jump without rebound movements starting from a half-squat position, keeping both knees bent at 90°, the trunk straight, and both hands on their hips. Previous counter-movements were disallowed. (iii) For the counter-movement jump, participants were required to perform an earlier fast counter-movement vertical jump in a standing position, with legs straight and both hands on their hips. (iv) For the Abalakov jump, participants were required to perform a vertical jump with freely co-ordinated arm and trunk movements. All LBES tests were performed twice, were recorded in centimetres and the maximum scores were used for analysis.

Potential confounders

Potential confounders included: city, gender, and PA in free-living conditions during an one-week period (seven consecutive days) measured as total counts assessed using a GT1M Monitor (ActiGraph®, Pensacola, FL, USA).

Procedures for the ActiGraph device, data collection, and data cleaning were previously described [42]. Briefly, a fieldworker researcher at each study site completed workshop training on instructing participants to use the device. The adolescents were instructed to wear the accelerometer on their lower back, on an elastic belt with an adjustable buckle, for seven consecutive days during their normal routine. They were also instructed to remove the accelerometer during swimming, showering, bathing, and at night. Data were collected in 15 s intervals. After downloading these data, PA levels were converted and expressed as an average PA in mean counts per minute. Data from 06.00 to 23.00 were analysed. Strings of 20 consecutive minutes recording zero counts were classified as non-wear periods and excluded from analyses [43]. Participants who did not record at least three days with a minimum of 8 h each wearing time were excluded from analyses. PA was expressed as cumulative counts during the 1-week wearing period.

Pubertal status was assessed by identifying sexual maturation (stages I–V) by a well-trained physician according to Tanner and Whitehouse [44]. This standard staging describes breast and pubic hair development in girls and genital and pubic hair development in boys.

Parental education was classified into one of three categories using a specific questionnaire adapted from the International Standard Classification of Education (ISCED) (http://www.uis.unesco.org/Library/Documents/isced97-en.pdf): 1, primary and lower education (ISCED levels 0, 1, and 2); 2, higher secondary (ISCED levels 3 and 4); and 3, tertiary (ISCED levels 5 and 6).

Adolescent BMI z-score was calculated using the lambda, mu, and sigma method where L reflects the Box-Cox power lamba, M the artithmetic mean of the measurement and S the coefficient of variation [45]. This method has been validated for several years by the International Obesity Task Force (IOTF) in order to develop global growth curves for children and adolescents [46]. This method allows a normal distribution of BMI values [47, 48].

Body composition (fat-free mass and fat mass) was assessed using skinfold thicknesses (biceps, triceps, subscapular, suprailiac, thigh and calf) measured in triplicate on the left side of the body with a Holtain calliper (range, 0–40 mm; precision, 0.2 mm) [49]. Body fat percentage was calculated using Slaughter's equations [50] and the fat-free mass percentage was derived by subtracting fat mass from total body weight.

Statistical analysis

Data are presented as mean ± standard deviation. Distribution normality was checked graphically and using the Shapiro–Wilk test. To assess potential bias related to missing or incomplete neonatal or PF data, these characteristics among included and excluded adolescents were compared using Student's *t* test for quantitative variables, chi-square test for categorical variables, and the Cochran–Armitage trend test for ordered categorical variables. To evaluate the magnitude of differences between analysed and non-analysed participants, we calculated the absolute standardised differences; a standardised difference >20% denotes a meaningful imbalance.

Associations between PF and perinatal factors were investigated with and without adjustment for predefined confounding factors. Linear mixed models were used, with PF measures as dependent variables, perinatal and confounding variables as independent fixed effects, and city as a random effect. Birth weight and breastfeeding duration were evaluated in separate models and then in a single regression model. To avoid case deletion, missing data were imputed by multiple imputations using the regression-switching approach (chained equations, $m = 10$ imputations) [51]. The imputation procedure was performed under the missing-at-random assumption using all variables, with the predictive mean-matching method for continuous variables and logistic regression (binary, ordinal, or multinomial) models for categorical variables. Rubin's rules were used to combine the estimates derived from multiple imputed datasets [52]. All statistical tests were performed at a two-tailed α level of 0.05. Data were analysed using SAS software (v. 9.4; SAS Institute Inc., Cary, NC, USA).

RESULTS

Table 1 presents perinatal characteristics and PF components for the whole sample. Comparisons between included and non-included adolescents are presented in supplemental Table 1, showing that the studied sample included less boys, more who were overweight or obese, and those with a higher educational level; however, absolute standardised differences did not exceed the 20% threshold.

Table 2 presents the associations between PF components and birth weight according to gender. Only UBMS by handgrip were positively associated with birth weight for boys and girls in all models.

Table 1. Perinatal characteristics and physical fitness parameters of the whole studied population ($n = 2231$).

Variable	N	Value
Perinatal characteristics		
Breastfeeding duration	2173	
0 month		479 (22.1)
until 3 months		750 (34.5)
3 to 5 months		700 (32.2)
6 months and more		244 (11.2)
Weight at birth (kg)	2231	3.4 ± 0.5
Z-score weight at delivery	2231	0.2 ± 1.1
Height at birth (cm)	2231	50.7 ± 2.7
Physical fitness components		
CRF by LSR; VO_2 max (*levels*)	1882	5.0 ± 2.6
Flexibility by Back-Saver sit (*cm*)	2214	23.1 ± 8.1
Speed/agility by 4×10 m shuttle run (*s*)	2139	12.2 ± 1.4
UBMS by Hang-Grip (*kg*)	2226	30.1 ± 8.5
UBMS by Flexed Arm Hang (*s*)	2098	14.0 ± 14.9
LBES by Standing Broad Jump (*cm*)	2203	162.3 ± 34.9
LBES by Squat Jump (*cm*)	1940	21.8 ± 7.4
LBES by Counter Movement Jump (*cm*)	1935	24.4 ± 7.3
LBES by Abalakov Jump (*cm*)	1931	28.9 ± 8.1

Values are in mean ± standard deviation except for breastfeeding duration (*n*, %).

CRF cardio respiratory fitness, *LSR* Léger shuttle run, *UBMS* upper body muscular strength, *LBES* lower body explosive strength.

Table 3 presents the associations between PF components and breastfeeding duration. When only study centre was adjusted (model 1), except for UBMS, all PF related to muscular strength and explosive strength components were associated with breastfeeding duration in boys. In girls, only UBMS, and LBES by standing broad jump and squat jump were associated with breastfeeding duration. When other confounding factors such as BMI z-score, fat-free mass, and fat mass were used (models 2 to 5), only LBES by standing broad jump was positively associated with breastfeeding duration.

Table 4 presents the associations between PF components that were significant in Tables 2 and 3 (birth weight and breastfeeding duration, respectively) combined in a multivariate regression analysis (Table 4). Independent of breastfeeding duration, UBMS by handgrip remained associated with birth weight in all adjusted models (models 1 to 5). In addition, independent of birth weight, LBES by standing broad jump and LBES by squat jump remained associated with breastfeeding duration only in model 2 in boys.

DISCUSSION

The main study finding was that neonatal factors (i.e. birth weight, breastfeeding duration), both separately and combined, were associated with only two PF components: muscular power and explosivity. This study is the first to analyse the effects of birth weight and breastfeeding duration on these PF characteristics in the same sample of European adolescents.

Positive associations between breastfeeding duration and LBES by standing broad jump were observed both in girls and boys in all models. LBES by standing broad jump involve rapid bursts of speed. This suggests that breastfeeding duration has a positive impact on PF components involving type II fast-twitch muscular fibres. The role of breastfeeding duration in muscle explosivity is particularly high when LBES by standing broad jump was considered because the β coefficient in that multiple regression

Table 2. Associations between physical fitness components and birth weight in the studied population according to gender.

	Model 1		Model 2		Model 3		Model 4		Model 5	
	β ± SEM	P	β ± SEM	P	β ± SEM	P	β ± SEM	P	β ± SEM	P
Boys (n = 985)										
CRF by LSR; VO_2 max (*level*)	−0.03 ± 0.08	0.74	0.02 ± 0.07	0.84	−0.03 ± 0.07	0.64	−0.01 ± 0.07	0.94	−0.02 ± 0.07	0.73
Flexibility by Back-Saver sit (*cm*)	0.21 ± 0.22	0.35	0.15 ± 0.22	0.50	0.20 ± 0.22	0.37	0.20 ± 0.22	0.36	0.16 ± 0.22	0.47
Speed/agility by 4×10 m shuttle run (*s*)	−0.03 ± 0.03	0.31	−0.04 ± 0.03	0.16	−0.03 ± 0.03	0.34	−0.04 ± 0.03	0.18	−0.03 ± 0.03	0.31
UBMS by Hang-Grip (*kg*)	0.71 ± 0.26	**0.007**	0.41 ± 0.18	**0.025**	0.55 ± 0.19	**0.004**	0.52 ± 0.19	**0.006**	0.35 ± 0.18	0.054
UBMS by Flexed Arm Hang (*s*)	0.05 ± 0.51	0.92	0.39 ± 0.44	0.37	−0.05 ± 0.41	0.90	0.16 ± 0.42	0.71	−0.07 ± 0.41	0.86
LBES by Standing Broad Jump (*cm*)	1.17 ± 0.92	0.20	1.32 ± 0.78	0.090	0.84 ± 0.73	0.25	1.12 ± 0.74	0.13	0.70 ± 0.74	0.35
LBES by Squat Jump (*cm*)	−0.02 ± 0.21	0.92	0.04 ± 0.19	0.84	−0.07 ± 0.18	0.70	−0.01 ± 0.18	0.96	−0.09 ± 0.18	0.64
LBES by Counter Movement Jump (*cm*)	0.26 ± 0.22	0.23	0.32 ± 0.19	0.093	0.20 ± 0.18	0.28	0.26 ± 0.18	0.14	0.18 ± 0.18	0.31
LBES by Abalakov Jump (*cm*)	0.12 ± 0.24	0.62	0.18 ± 0.21	0.39	0.04 ± 0.19	0.83	0.12 ± 0.19	0.53	0.04 ± 0.19	0.85
Girls (n = 1246)										
CRF by LSR; VO_2 max (*level*)	0.06 ± 0.05	0.24	0.08 ± 0.05	0.11	0.08 ± 0.05	0.12	0.10 ± 0.05	0.051	0.07 ± 0.05	0.16
Flexibility by Back-Saver sit (*cm*)	0.21 ± 0.20	0.29	0.17 ± 0.20	0.39	0.21 ± 0.20	0.28	0.23 ± 0.20	0.25	0.18 ± 0.20	0.37
Speed/agility by 4 × 10 m shuttle run (*s*)	−0.03 ± 0.03	0.37	−0.04 ± 0.03	0.23	−0.04 ± 0.03	0.22	−0.05 ± 0.03	0.11	−0.03 ± 0.03	0.29
UBMS by Hang-Grip (*kg*)	0.49 ± 0.12	**<0.001**	0.40 ± 0.11	**<0.001**	0.47 ± 0.12	**<0.001**	0.39 ± 0.11	**<0.001**	0.25 ± 0.11	**0.024**
UBMS by Flexed Arm Hang (*s*)	−0.40 ± 0.23	0.085	−0.22 ± 0.22	0.32	−0.28 ± 0.21	0.19	−0.16 ± 0.22	0.45	−0.36 ± 0.21	0.086
LBES by Standing Broad Jump (*cm*)	0.40 ± 0.65	0.54	0.47 ± 0.63	0.45	0.46 ± 0.60	0.44	0.72 ± 0.61	0.24	0.23 ± 0.61	0.71
LBES by Squat Jump (*cm*)	0.02 ± 0.15	0.89	0.09 ± 0.14	0.53	0.08 ± 0.14	0.58	0.14 ± 0.14	0.31	0.08 ± 0.14	0.57
LBES by Counter Movement Jump (*cm*)	−0.10 ± 0.14	0.47	−0.03 ± 0.14	0.77	−0.05 ± 0.13	0.68	0.01 ± 0.13	0.93	−0.06 ± 0.13	0.66
LBES by Abalakov Jump (*cm*)	0.02 ± 0.16	0.92	0.10 ± 0.15	0.51	0.07 ± 0.14	0.61	0.15 ± 0.15	0.31	0.06 ± 0.15	0.70

CRF cardio respiratory fitness, *LSR* Léger shuttle run, *UBMS* upper body muscular strength, *LBES* lower body explosive strength.
β (±SEM) and *P* value were calculated after multiple imputations ($m = 10$) to handle missing data.
Model 1: adjusted for city.
Model 2: adjusted for city, age, physical activity during whole week, pubertal status, father education level, mother education level, Z-score BMI.
Model 3: adjusted for city, age, physical activity during whole week, pubertal status, father education level, mother education level, fat free mass.
Model 4: adjusted for city, age, physical activity during whole week, pubertal status, father education level, mother education level, fat mass.
Model 5: adjusted for city, age, physical activity during whole week, pubertal status, father education level, mother education level, fat free mass and fat mass.
Bold values indicates statistically significant ($p < 0.05$) values.

Table 3. Associations between physical fitness components and breastfeeding duration according to gender.

	Model 1		Model 2		Model 3		Model 4		Model 5	
	β ± SEM	*P*	β ± SEM	*P*	β ± SEM	*P*	β ± SEM	*P*	β ± SEM	*P*
Boys (n = 985)										
CRF by LSR; VO_2 max (*level*)	0.10 ± 0.09	0.28	−0.01 ± 0.09	0.90	−0.05 ± 0.08	0.53	−0.04 ± 0.08	0.63	−0.05 ± 0.08	0.55
Flexibility by Back-Saver sit (*cm*)	−0.07 ± 0.27	0.79	−0.04 ± 0.27	0.87	−0.10 ± 0.27	0.70	−0.09 ± 0.27	0.74	−0.11 ± 0.27	0.69
Speed/agility by 4 × 10 m shuttle run (*s*)	−0.06 ± 0.04	0.10	−0.03 ± 0.04	0.42	−0.01 ± 0.03	0.78	−0.01 ± 0.03	0.67	−0.01 ± 0.03	0.78
UBMS by Hang-Grip (*kg*)	0.28 ± 0.33	0.39	0.11 ± 0.23	0.63	0.04 ± 0.24	0.89	0.08 ± 0.24	0.73	−0.01 ± 0.23	0.98
UBMS by Flexed Arm Hang (*s*)	1.53 ± 0.60	**0.011**	0.87 ± 0.52	0.091	0.54 ± 0.49	0.26	0.66 ± 0.49	0.18	0.54 ± 0.49	0.27
LBES by Standing Broad Jump (*cm*)	3.58 ± 1.10	**0.001**	2.33 ± 0.95	**0.015**	1.83 ± 0.90	**0.043**	2.01 ± 0.91	**0.028**	1.80 ± 0.90	**0.046**
LBES by Squat Jump (*cm*)	0.76 ± 0.27	**0.005**	0.53 ± 0.25	**0.035**	0.43 ± 0.24	0.072	0.47 ± 0.24	0.056	0.43 ± 0.24	0.073
LBES by Counter Movement Jump (*cm*)	0.74 ± 0.27	**0.006**	0.47 ± 0.24	0.056	0.36 ± 0.23	0.12	0.40 ± 0.24	0.094	0.36 ± 0.23	0.13
LBES by Abalakov Jump (*cm*)	0.71 ± 0.29	**0.016**	0.40 ± 0.26	0.13	0.26 ± 0.24	0.29	0.30 ± 0.25	0.23	0.26 ± 0.24	0.29
Girls (n = 1246)										
CRF by LSR; VO_2 max (*level*)	0.11 ± 0.06	0.062	0.02 ± 0.06	0.74	0.01 ± 0.06	0.84	0.01 ± 0.06	0.83	0.01 ± 0.06	0.82
Flexibility by Back-Saver sit (*cm*)	0.38 ± 0.23	0.098	0.32 ± 0.23	0.16	0.29 ± 0.23	0.21	0.29 ± 0.23	0.20	0.30 ± 0.23	0.19
Speed/agility by 4 × 10 m shuttle run (*s*)	−0.04 ± 0.04	0.30	0.01 ± 0.04	0.93	0.01 ± 0.04	0.80	0.01 ± 0.04	0.82	0.01 ± 0.04	0.82
UBMS by Hang-Grip (*kg*)	−0.09 ± 0.14	0.54	0.06 ± 0.13	0.64	0.02 ± 0.14	0.87	0.06 ± 0.13	0.66	0.06 ± 0.13	0.64
UBMS by Flexed Arm Hang (*s*)	0.56 ± 0.27	**0.043**	0.14 ± 0.25	0.57	0.13 ± 0.24	0.59	0.14 ± 0.25	0.59	0.14 ± 0.24	0.56
LBES by Standing Broad Jump (*cm*)	2.70 ± 0.76	**<0.001**	1.58 ± 0.73	**0.031**	1.43 ± 0.70	**0.042**	1.46 ± 0.72	**0.041**	1.47 ± 0.70	**0.036**
LBES by Squat Jump (*cm*)	0.35 ± 0.17	**0.046**	0.16 ± 0.18	0.36	0.14 ± 0.17	0.42	0.14 ± 0.17	0.42	0.14 ± 0.17	0.43
LBES by Counter Movement Jump (*cm*)	0.17 ± 0.17	0.31	−0.03 ± 0.17	0.86	−0.05 ± 0.16	0.76	−0.05 ± 0.16	0.76	−0.05 ± 0.16	0.76
LBES by Abalakov Jump (*cm*)	0.25 ± 0.18	0.17	−0.01 ± 0.17	0.95	−0.03 ± 0.16	0.85	−0.03 ± 0.17	0.86	−0.03 ± 0.16	0.86

CRF cardio respiratory fitness, *LSR* Léger shuttle run, *UBMS* upper body muscular strength, *LBES* lower body explosive strength.
β (±SEM) and *P* value were calculated after multiple imputations ($m = 10$) to handle missing data.
Model 1: adjusted for city.
Model 2: adjusted for city, age, physical activity during whole week, pubertal status, father education level, mother education level, Z-score BMI.
Model 3: adjusted for city, age, physical activity during whole week, pubertal status, father education level, mother education level, fat free mass.
Model 4: adjusted for city, age, physical activity during whole week, pubertal status, father education level, mother education level, fat mass.
Model 5: adjusted for city, age, physical activity during whole week, pubertal status, father education level, mother education level, fat free mass and fat mass.
Bold values indicates statistically significant ($p < 0.05$) values.

Table 4. Associations between physical fitness components combined with birth weight and breastfeeding duration according to gender.

	Model 1		Model 2		Model 3		Model 4		Model 5	
	β ± SEM	P	β ± SEM	P	β ± SEM	P	β ± SEM	P	β ± SEM	P
Boys (n = 985)										
UBMS by Hang-Grip (*kg*)										
Birth weight	0.70 ± 0.26	**0.008**	0.40 ± 0.18	**0.026**	0.55 ± 0.19	**0.004**	0.52 ± 0.19	**0.006**	0.35 ± 0.18	0.052
Breastfeeding duration	0.23 ± 0.33	0.48	0.08 ± 0.23	0.72	−0.01 ± 0.24	0.99	0.05 ± 0.24	0.85	−0.03 ± 0.23	0.90
UBMS by Flexed Arm Hang (*s*)										
Birth weight	−0.03 ± 0.51	0.96	0.35 ± 0.44	0.42	−0.08 ± 0.41	0.85	0.13 ± 0.42	0.77	−0.10 ± 0.41	0.81
Breastfeeding duration	1.53 ± 0.60	**0.011**	0.85 ± 0.52	0.10	0.55 ± 0.49	0.26	0.65 ± 0.49	0.19	0.54 ± 0.49	0.26
LBES by Standing Broad Jump (cm)										
Birth weight	0.99 ± 0.92	0.28	1.21 ± 0.78	0.12	0.76 ± 0.73	0.30	1.03 ± 0.74	0.17	0.62 ± 0.74	0.41
Breastfeeding duration	3.51 ± 1.10	**0.001**	2.25 ± 0.95	**0.019**	1.78 ± 0.90	**0.049**	1.94 ± 0.92	**0.034**	1.76 ± 0.90	0.051
LBES by Squat Jump (*cm*)										
Birth weight	−0.06 ± 0.21	0.77	0.01 ± 0.19	0.96	−0.09 ± 0.18	0.62	−0.03 ± 0.18	0.86	−0.11 ± 0.19	0.56
Breastfeeding duration	0.77 ± 0.27	**0.005**	0.53 ± 0.25	**0.036**	0.44 ± 0.24	0.069	0.47 ± 0.24	0.056	0.43 ± 0.24	0.070
LBES by Counter Movement Jump (*cm*)										
Birth weight	0.22 ± 0.22	0.30	0.30 ± 0.19	0.12	0.18 ± 0.18	0.32	0.24 ± 0.18	0.18	0.17 ± 0.18	0.36
Breastfeeding duration	0.72 ± 0.27	**0.008**	0.45 ± 0.24	0.068	0.35 ± 0.23	0.14	0.38 ± 0.24	0.11	0.34 ± 0.23	0.14
LBES by Abalakov Jump (*cm*)										
Birth weight	0.08 ± 0.24	0.73	0.16 ± 0.21	0.44	0.03 ± 0.19	0.88	0.11 ± 0.20	0.58	0.03 ± 0.20	0.89
Breastfeeding duration	0.70 ± 0.29	**0.018**	0.39 ± 0.26	0.14	0.25 ± 0.24	0.30	0.29 ± 0.25	0.24	0.25 ± 0.24	0.30
Girls (n = 1246)										
UBMS by Hang-Grip (*kg*)										
Birth weight	0.51 ± 0.12	**<0.001**	0.40 ± 0.11	**<0.001**	0.47 ± 0.12	**<0.001**	0.39 ± 0.11	**<0.001**	0.24 ± 0.11	**0.026**
Breastfeeding duration	−0.14 ± 0.14	0.32	0.02 ± 0.13	0.87	−0.02 ± 0.13	0.85	0.02 ± 0.13	0.90	0.03 ± 0.13	0.79
UBMS by Flexed Arm Hang (*s*)										
Birth weight	−0.45 ± 0.23	0.054	−0.23 ± 0.22	0.29	−0.29 ± 0.21	0.17	−0.18 ± 0.22	0.41	−0.38 ± 0.21	0.076
Breastfeeding duration	0.60 ± 0.27	**0.028**	0.17 ± 0.25	0.51	0.16 ± 0.25	0.51	0.15 ± 0.25	0.54	0.18 ± 0.24	0.45
LBES by Standing Broad Jump (cm)										
Birth weight	0.18 ± 0.65	0.78	0.35 ± 0.63	0.58	0.36 ± 0.60	0.55	0.61 ± 0.62	0.32	0.11 ± 0.61	0.86
Breastfeeding duration	2.68 ± 0.76	**<0.001**	1.54 ± 0.73	**0.036**	1.40 ± 0.71	**0.048**	1.40 ± 0.72	0.051	1.46 ± 0.70	**0.038**
LBES by Squat Jump (*cm*)										
Birth weight	−0.01 ± 0.15	0.95	0.08 ± 0.14	0.59	0.07 ± 0.14	0.63	0.13 ± 0.14	0.35	0.07 ± 0.14	0.62
Breastfeeding duration	0.35 ± 0.18	**0.046**	0.15 ± 0.18	0.38	0.13 ± 0.17	0.45	0.13 ± 0.17	0.47	0.13 ± 0.17	0.45
LBES by Counter Movement Jump (*cm*)										
Birth weight	−0.12 ± 0.14	0.41	−0.04 ± 0.14	0.78	−0.05 ± 0.13	0.70	0.02 ± 0.13	0.91	−0.06 ± 0.13	0.67
Breastfeeding duration	0.18 ± 0.17	0.28	−0.02 ± 0.16	0.88	−0.05 ± 0.16	0.78	−0.05 ± 0.16	0.75	−0.04 ± 0.16	0.78
LBES by Abalakov Jump (*cm*)										
Birth weight	−0.01 ± 0.16	0.97	0.10 ± 0.15	0.50	0.08 ± 0.15	0.60	0.15 ± 0.15	0.30	0.06 ± 0.15	0.69
Breastfeeding duration	0.26 ± 0.18	0.17	-0.02 ± 0.17	0.90	−0.04 ± 0.17	0.82	−0.05 ± 0.17	0.79	−0.03 ± 0.17	0.83

UBMS upper body muscular strength, *LBES* lower body explosive strength.
β (±SEM) and *P* value were calculated after multiple imputations ($m = 10$) to handle missing data.
Model 1: adjusted for city.
Model 2: adjusted for city, age, physical activity during whole week, pubertal status, father education level, mother education level, Z-score BMI.
Model 3: adjusted for city, age, physical activity during whole week, pubertal status, father education level, mother education level, fat free mass.
Model 4: adjusted for city, age, physical activity during whole week, pubertal status, father education level, mother education level, fat mass.
Model 5: adjusted for city, age, physical activity during whole week, pubertal status, father education level, mother education level, fat free mass and fat mass.
Bold values indicates statistically significant ($p < 0.05$) values.

reached 3.58 in boys and 2.70 in girls, twice as high as the other. This is consistent with the previously described role of breastfeeding in type II fast-twitch fibre development and muscular explosivity. Indeed, it has been shown that several breastmilk compounds including enzymes, adipokines, and vitamins induce the development of these specific muscle fibres rather than purely muscle mass [53–55]. A positive association was observed in boys for PF components involved type II fast-twitch muscular fibres (i.e. LBES tests) and breastfeeding duration when model 1 was used, without body composition as covariate. When body composition was used as covariate, the positive association disappeared suggesting a role of body size and body composition in the interpretation of PF component analysis.

A positive association between birth weight and UBMS by hand-grip was observed both in girls and boys, in all models. UBMS by hand-grip assesses muscle strength, suggesting a role of birth weight in muscle strength development. Birth weight acts as an index of gestational period condition [56]. The gestational period is the growth period for skeletal fibre composition and muscle blood irrigation vessels [57]. Among others, the gestational period is a time when metabolic pathways and type I fibre skeletal muscle develop [58]. Type I fibre muscles are involved in muscular power [59]. In this context, birth weight increases muscular power for long utilisation of muscle, a parameter assessed by handgrip test [60]. Handgrip is uninfluenced by body composition because multivariate models 2 to 5 (BMI, fat, and fat-free mass, respectively) were not significant. This PF test is not dependent on gravitational forces induced by body weight or its components. This is also true for standing broad jump, in which BMI and fat mass influenced the association between breastfeeding duration and standing broad jump.

The analysis of association between PF component combined with birth weight and breast feeding duration confirms that breastfeeding duration is associated with PF components involving type II fast-twitch muscular fibres (i.e. LBES tests) especially in boys without body composition as covariate. When body composition was used as covariate, the positive association disappeared for all PF jump tests (Bosco series) suggesting that the weight and body composition are highly dependent on gravitational forces. The standing broad jump do not depend on gravitational forces because it use horizontal speed displacement.

Some study limitations should be acknowledged. Among the main limitation was the cross-sectional design of the study, which prevented us from deducing causation. Functional characteristics of the musculature is susceptible to modifications due to ethnic factors and competitive sport training not analysed in this study. The study strengths is the young sample's age as adolescence is an optimal period to analyse the impacts of perinatal factors on health. This is because, at this age, individuals have had less exposure to unfavourable environmental and lifestyle factors compared to adults (e.g. smoking, drinking alcohol). Other strengths include our large sample size from 9 European cities, our use of standardised procedures, the inclusion of several confounding factors in the analyses, the PF components assessed herein were within European PF normal ranges, and objective assessment of PF with the strongest criterion-related validity were used.

In conclusion, this study shows that perinatal factors have a positive effect on muscular strength and, indirectly, on health [61]. Having high muscular strength in adolescence is essential since low muscular fitness in adolescence persists into adulthood [21, 22] and is associated with high adiposity level and poor adult cardio-metabolic health [20, 23]. Birth weight and breastfeeding duration have different effects on muscular strength components. Birth weight positively influences muscular power. Breastfeeding duration positively influences muscular explosivity. Low birth weight infants should be exposed to more PA to preserve this functioning in later life, and breastfeeding must be encouraged in all populations [62].

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AUTHOR CONTRIBUTIONS

Laurent Béghin and Jérémy Vanhelst designed the data collection instruments, coordinated and supervised data collection, conducted the initial analyses and drafted the initial manuscript. Elodie Drumez conducted the initial analyses, statistical analysis and drafted the initial manuscript. Mathilde Kersting, Denes Molnar, Anthony Kafatos and Eva Karaglani designed data collection instruments, coordinated and supervised data collection and critically reviewed the manuscript for important intellectual content. Stefaan De Henauwn, Kurt Wildhalm, Luis A. Moreno and Frédéric Gottrand conceptualised and designed the study, supervised data collection, coordinated the study and critically reviewed the manuscript for important intellectual content. And all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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