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Prenatal and childhood growth and physical performance in old age—findings from the Helsinki Birth Cohort Study 1934–1944

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Abstract Health in adulthood is in part a consequence of development and growth taking place during sensitive periods in early life. It has not been explored previously whether early growth is associated with physical performance in old age from a life course perspective taking into account health-related behavior, biological risk factors, and early life experiences. At a mean age of 71 years, physical performance was assessed using the Senior Fitness Test (SFT) in 1078 individuals belonging to the Helsinki Birth Cohort Study. We used multiple linear regression analysis to assess the association between the SFT physical fitness scores and individual life course measurements. Several adult characteristics were associated with physical performance including socioeconomic status, lifestyle factors, and adult anthropometry. Higher birth weight and length were associated with better physical performance, even after adjusting for potential confounders (all p values <0.05). The strongest individual association between life course measurements and physical performance in old age was found for adult body fat percentage. However, prenatal growth was independently associated with

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physical performance seven decades later. These findings suggest that physical performance in old age is at least partly programmed in early life.

Keywords Physical performance · Senior Fitness Test · Prenatal growth · Birth weight · Aging · Physical fitness

Introduction

Globally, mean age is rapidly increasing, with a larger number of people surviving to very old age (World Health Organization 2011). In old age, physical function describes a person's ability to perform various common activities in the course of daily life and reflects overall health, lifestyle, genetic predisposition, and socioeconomic position. The assessment of physical performance typically incorporates aspects of strength, mobility, freedom of movement, balance, and coordination (Rikli and Jones 1999).

The framework of life course epidemiology proposes that development and growth taking place during the life course, including prenatal life and childhood, have long-term effects and consequences on health and functioning in adulthood (Ben-Shlomo and Kuh 2002; von Bonsdorff et al. 2011; Power et al. 2013; von Bonsdorff et al. 2015; Stewart et al. 2015). Within this framework, the Developmental Origins of Health and Disease (DOHaD) hypothesis focuses upon later health consequences of exposures occurring in prenatal life, infancy, and childhood. Studies in the DOHaD field have repeatedly shown that a small body size at birth and slow growth during infancy predict several non-communicable diseases (NCDs), including cardiovascular disease, type 2 diabetes, and depression (Barker et al. 1989, 1993, 2005; Rich-Edwards et al. 1999; Räikkönen et al. 2007; Hanson and Gluckman 2014). These NCDs are associated with decreased physical performance, which can also be present in the absence of manifest disease. Poor physical performance in old age has negative health consequences as it predisposes to disability, morbidity, and premature mortality (Guralnik et al. 1995, 1996; Cooper et al. 2010; Studenski et al. 2011). Further, poor physical performance has been shown to lead to loss of independence (von Bonsdorff et al. 2006; Wallman et al. 2006; Legrand et al. 2014). So far, there are only a few studies showing that early development is independently associated with physical capability and functioning in midlife (von Bonsdorff et al. 2011; Dodds et al. 2012; Kuh et al. 2006; Ylihärsilä et al. 2007). To our knowledge, it has not been explored whether early growth is associated with physical performance in old age from a life course perspective simultaneously taking into account adult health-related behavior, biological risk factors, and early life experiences, and we hypothesized that early growth is independently associated with physical performance in later life.

Here, we report from a life course perspective on factors associated with physical performance in later life at the mean age of 71 years using an objective measure, i.e., the Senior Fitness Test (SFT), in 1078 individuals belonging to the Helsinki Birth Cohort Study.

Study population and measures

The Helsinki Birth Cohort Study (HBCS) includes 13,345 individuals born in Helsinki between 1934 and 1944, who visited child welfare clinics in the city and who were living in Finland in 1971 when a unique personal identification number was assigned to all Finnish residents. The majority of the subjects also went to school in the city of Helsinki (Eriksson et al. 2006; Osmond et al. 2007; Ylihärsilä et al. 2008). Data on neonatal characteristics, including weight and length, were extracted from hospital birth records and infancy and childhood weight and height from child welfare clinic and school health records. These have been described in detail previously (Barker et al. 2005; Eriksson et al. 2006). Body mass index was calculated as (weight (kg)/height (m)^2). Childhood socioeconomic status was evaluated on the basis of the father's occupation indicated by the highest occupational class extracted from the birth and child welfare and school health records.

In the year 2000, a random sample of subjects from HBCS were invited to participate in a clinical examination (Barker et al. 2005). In order to achieve a sample size in excess of 2000 people for the clinical part of the study, we selected 2901 subjects for evaluation. Of these, 2003 participated at an average age of 61 years in the examinations conducted between the years 2001 and 2004 (Ylihärsilä et al. 2008). From the original clinical study cohort (n=2003), 1404 people who were alive and living within 100 km distance from our study clinic in Helsinki were invited to participate in a new clinical follow-up in 2011. A total of 1094 participants attended the clinical examination between 2011 and 2013. Of these, 1078 (603 women and 475 men) had adequate information on physical performance tests and

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were included in this study. The participants in the present study were 67 to 77 years of age. Those not participating declined mostly due to their own or a family member's health conditions. The participants were measured for weight and height at the clinical examination at a mean age of 71 years, and lean body mass was assessed with bioelectrical impedance by using the InBody 3.0 eight-polar tactile electrode system (Biospace Co., Ltd., Seoul, Korea) (Bedogni et al. 2002). Participants' smoking status, physical activity, health characteristics, living circumstances, and other characteristics were assessed using questionnaires at the clinical examination. Blood was drawn for assessment of fasting plasma glucose. Blood pressure was measured from the right arm while the subject was in the sitting position, and it was recorded as the mean of two successive readings from a standard sphygmomanometer (Omron Matsusaka Europe, Hoofdorp, the Netherlands). All measurements were done by trained study nurses.

Register data from Statistics Finland were used to indicate adult socioeconomic position. The highest occupational class at 5-year intervals between 1970 and 1995 was categorized into upper middle class, lower middle class, self-employed, and laborers. Data on educational attainment was obtained from Statistics Finland.

Physical fitness

In the clinical follow-up examination, detailed physical fitness tests were done by using a validated Senior Fitness Test battery (SFT) (Rikli and Jones 1999, 2013). We used a modified test battery which consists of five measures of physical fitness: (1) number of chair stands during 30 s to assess lower-body strength, (2) arm curl to assess upper-body strength (curling the weight, 2 kg for women and 3 kg for men, through the full range of motion as many times as possible during 30 seconds), (3) chair sit and reach to assess the lower-body (hamstring) flexibility (distance between fingers and toe), (4) a 6-min walk test to measure aerobic endurance (distance walked in 6 min), and (5) back scratch to assess upper-body (shoulder) flexibility (with one hand reaching over shoulder and the other one up middle of back, distance between extended middle fingers). All measurements were performed by a team of trained research assistants.

For each test, the scores of the participants were also classified with respect to percentile tables of normative data for each 5-year age group (Rikli and Jones 2013). A rating from 1 to 20 was given according to each 5-percentile range, with 1 being the worst performance (score below the 5th percentile), 2 the score from the 5th to the 9th percentile, and 20 the best performance (in or above the 95th percentile). Then we calculated an overall score, which was the sum of the normalized scores for the five SFT test components. The overall SFT score varied between 5 and 100.

Ethics statement

The study complies with the guidelines of the Declaration of Helsinki. The study was approved by the Coordinating Ethics Committee of the Hospital District of Helsinki and Uusimaa. All participants gave a written, informed consent.

Statistical analyses

We analyzed the age- and sex-standardized percentile scores for each of the five components of the SFT test (Rikli and Jones 1999) and used the average of the scores as an overall measure of physical fitness. We used multiple linear regression analysis to assess the association between physical fitness scores and measurements of size and growth early in life. Figure 1 illustrates the sequence of models we used to examine the influence of potential confounding life course measurements. In model 1, we assessed the net effect of early body size on late life physical functioning, only controlling for sex and for the age of the participants. In model 2, we addressed whether any associations were the result of confounding by also including socioeconomic status, measured by education and occupation of the father and subject, and three measures of adult lifestyle—smoking, physical activity, and living circumstances. In model 3, we then considered whether any association between early body size and physical functioning was attributable to the known association of early body size with blood pressure and glucose metabolism by further including systolic blood pressure and fasting glucose concentration. Finally, in model 4, we further controlled for adult anthropometry to determine whether any remaining association between early body size and physical functioning was explained by these measures both being linked with adult size.

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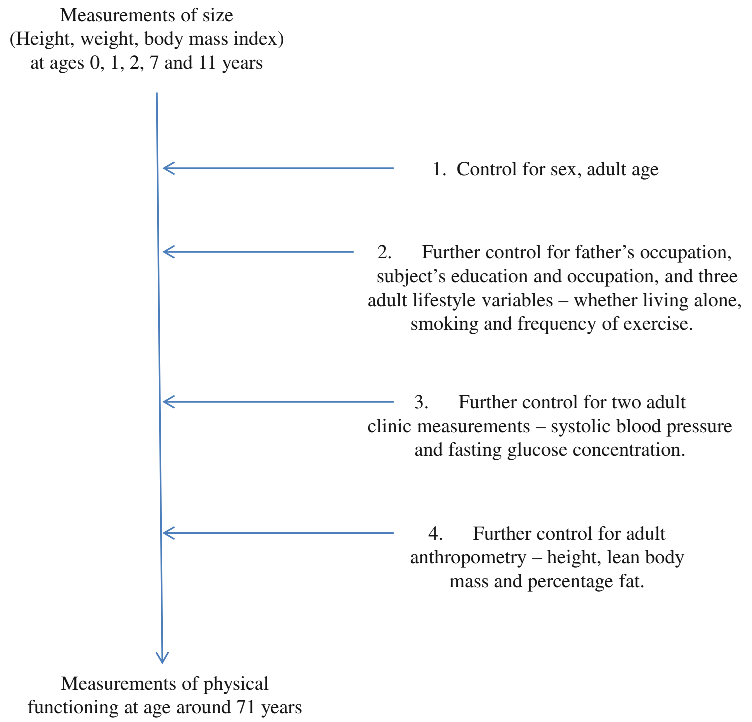

Fig. 1 Diagram illustrating which variables were included in the analyses as potential confounders

In supplementary analyses, we assessed growth in infancy and childhood by using the conditional method (Tu et al. 2013).

Results

The analyses included 1078 subjects, 475 men and 603 women. The mean age of the participants was 71.3 years (range 66.9–79.1 years) at the follow-up clinical study visit when physical fitness was assessed. Characteristics of the study cohort along with the individual components of the Rikli-Jones SFT are shown in Table 1 separately for men and women. The variables are grouped from 1 to 4 based on the model stage at which they are first introduced. The results from the SFT components are presented as means and mean age-adjusted percentile result for the test.

Table 2 shows separate regression analyses for men and women of overall SFT score in which the potential predictors of physical function in models 1 to 4 are included, but no body size or growth measurement. Educational attainment and adult smoking, exercise, fasting glucose, and body fat percentage were all associated with the overall SFT score. There were gender differences observed as shown in Table 2.

Table 3 shows the regression coefficients for the prediction of the overall Rikli-Jones SFT score expressed as a z score using length/height, weight, and body mass index at birth, 1, 2, 7, and 11 years in models with different sets of covariates. In model 4, adjustments were made for socioeconomic and lifestyle factors, age, health, and anthropometric variables. Table 3 shows that birth length, birth weight, and body mass index at birth were all inversely associated with the overall Rikli-Jones test score after adjustment for confounders (all p values <0.05).

Supplementary Table 1 and 2 show the same analysis separately for males and females. Weight and length at birth and at 1 year were all associated with the overall SFT score in men, but did not reach statistical significance in women. Height at 1 and 2 years were positively associated with physical fitness in men, while height at 7 and 11 years were inversely associated with physical fitness. Formal assessment of the sex differences

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Table 1 Characteristics of the men and women in the Helsinki Birth Cohort Study

Measurement	Men (*N*=475)		Women (*N*=603)	
	Mean	SD	Mean	SD
Neonatal, infant, and childhood size				
Length, height (cm) at age				
Birth	50.7	2.0	50.1	1.8
1 year	76.7	2.4	75.0	2.4
2 years	86.8	2.9	85.6	2.9
7 years	121.1	4.7	120.1	4.5
11 years	141.8	5.6	141.7	6.4
Weight (kg) at age				
Birth	3.482	0.483	3.368	0.440
1 year	10.5	1.0	9.9	1.0
2 years	12.4	1.1	11.9	1.1
7 years	22.7	2.5	22.3	2.8
11 years	33.9	4.3	34.2	5.5
Body mass index (kg/m^2) at age				
Birth	13.5	1.3	13.4	1.2
1 year	17.9	1.4	17.5	1.3
2 years	16.7	1.2	16.4	1.2
7 years	15.5	1.1	15.5	1.3
11 years	16.9	1.4	17.0	1.9
1. Age at clinic (years)	70.8	2.6	71.0	2.8
2. Father's occupation (*r*/*n*, %)				
Upper middle class	72/475	15.2	61/603	10.1
Lower middle class	96/475	20.2	114/603	18.9
Laborer	287/475	60.4	406/603	67.3
Unknown	20/475	4.2	22/603	3.6
2. Education level (*r*/*n*, %)				
Basic	122/465	26.2	247/593	41.7
Upper secondary	214/465	46.0	235/593	39.6
Lower tertiary	54/465	11.6	74/593	12.5
Upper tertiary	75/465	16.1	37/593	6.2
2. Adult occupation (*r*/*n*, %)				
Upper/lower middle class	165/475	34.7	147/603	24.4
Self-employed	135/475	28.4	355/603	58.9
Laborer	138/475	29.1	63/603	10.4
Unknown	37/475	7.8	38/603	6.3
2. Adult lifestyle (*r*/*n*, %)				
Living alone	64/466	13.7	240/590	40.7
Current smoker	60/467	12.8	62/598	10.4
Exercises 3+ times per week	304/460	66.1	337/596	56.5
3. Adult clinical measurements				
Systolic BP (mmHg)	151.0	20.0	151.7	21.9
Diastolic BP (mmHg)	84.7	9.8	83.1	10.5
Hypertension (*r*/*n*, %)	228/468	48.7	290/598	48.5
Fasting plasma glucose (mmol/l)	5.9	1.1	5.6	0.8
Diabetes (*r*/*n*, %)	82/468	17.5	75/598	12.5
4. Adult anthropometry				
Height (cm)	176.2	6.0	162.3	5.7
Weight (kg)	83.3	13.0	71.7	13.2
Body mass index (kg/m^2)	26.8	3.8	27.3	5.0
Lean body mass (kg)	63.2	7.6	46.1	5.5
Fat mass (kg)	20.0	7.7	25.6	9.4
Body fat (%)	23.5	5.9	34.7	6.9
Rikli-Jones test results				
Chair stands (*n*)	11.8	2.2	10.9	2.2
Percentile	28.8	15.8	32.3	19.5
Arm curls (*n*)	17.1	3.7	14.7	3.2
Percentile	46.5	23.7	51.2	23.5
Chair sit and reaches (cm)	−7.3	12.7	2.6	10.4
Percentile	36.9	28.4	49.4	29.2
Distance walked in 6 min (m)	561	98	498	91
Percentile	53.3	27.7	51.4	27.1
Back scratch (cm)	−13.7	13.0	−5.2	10.2
Percentile	47.6	29.6	50.8	29.3
Mean total percentile	42.7	16.9	46.9	17.9

for model 4 analyses is shown in Supplementary Table 3, as is formal assessment of the linearity of the associations.

Table 4 shows the associations of the individual components of the SFT with neonatal, infant, and childhood size, with adjustments according to model 4. As shown, several of the individual components of the SFT were associated with early growth after adjustment for confounders and mediators. Supplementary Table 3 shows the results of tests for difference in the regression coefficients across the five SFT components. These tests suggest no particular difference—early size predicting each of the outcomes rather consistently.

Supplementary Table 4 shows the association between early growth and overall SFT score. The overall score is negatively associated with increase in height and weight in early childhood. It is also associated with greater adolescent height gain and lesser adult BMI gain.

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Table 2 Regression coefficients for the prediction of the overall Rikli-Jones test result (expressed as a *z* score) using life course measures

Predictor	Men (*N*=475)			Women (*N*=603)		
	b	95 % CI	*p*	*b*	95 % CI	*p*
Father's occupation						
Upper middle class	−0.29	−4.41 to 3.82	0.89	0.28	−4.18 to 4.73	0.90
Lower middle class	−2.08	−5.58 to 1.42	0.24	2.32	−1.12 to 5.76	0.19
Laborer	Base	–	–	Base	–	–
Education level						
Basic	Base	–	–	Base	–	–
Upper secondary	1.74	−1.77 to 5.25	0.33	4.06	1.08 to 7.03	0.008
Lower tertiary	10.6	4.70 to 16.4	<0.001	2.49	−2.07 to 7.04	0.28
Upper tertiary	6.32	0.62 to 12.0	0.03	0.44	−5.71 to 6.60	0.89
Adult occupation						
Upper/lower middle class	−0.62	−4.93 to 3.70	0.78	3.33	−0.19 to 6.84	0.06
Self-employed	Base	–	–	Base	–	–
Laborer	0.37	−3.29 to 4.03	0.84	3.34	−3.02 to 9.70	0.30
Adult lifestyle (1=yes; 0=no)						
Living alone	−1.38	−5.37 to 2.61	0.50	−3.28	−5.95 to −0.62	0.02
Current smoker	−9.19	−13.3 to −5.02	<0.001	−8.85	−13.1 to −4.57	<0.001
Exercises ≥3 times/week	4.94	2.02 to 7.86	0.001	2.99	0.33 to 5.64	0.03
Adult clinical measurements						
Age (years)	0.00	−0.55 to 0.55	0.99	−0.03	−0.51 to 0.45	0.90
Systolic BP (mmHg)	0.01	−0.06 to 0.08	0.74	0.01	−0.05 to 0.07	0.64
Fasting glucose (mmol/l)	−1.71	−2.98 to −0.44	0.008	−2.13	−3.78 to −0.47	0.01
Adult anthropometry						
Height (cm)	−0.07	−0.42 to 0.28	0.69	−0.33	−0.67 to 0.01	0.06
Lean body mass (kg)	0.19	−0.09 to 0.47	0.18	0.21	−0.15 to 0.56	0.26
Body fat (%)	−1.10	−1.37 to −0.82	<0.001	−1.07	−1.31 to −0.84	<0.001

All variables are considered simultaneously

b regression coefficient, *CI* confidence interval

Discussion

In the present study, we assessed the associations between early growth, adult characteristics, and anthropometrics and physical performance at an average age of 71 years from a life course perspective. Exposures taking place over the life course, including prenatal life and childhood, have been proposed to have long-term effects on health and physical performance at an older age, and this is to our knowledge the first study which confirms this assumption in people over 70 years of age. The strongest predictor of physical performance in old age was adult body fat percentage. However, both prenatal growth and growth during childhood independently predicted physical fitness up to seven decades later. These findings suggest that physical performance in old age is at least partly programmed in early life.

In the present study, we used the Rikli-Jones Senior Fitness Test to assess physical performance. The SFT measures strength, endurance, agility as well as dynamic balance that are all associated with maintaining physical independence in old age (Rantanen et al. 1999, 2001; Rikli and Jones 1999, 2013). In other words, the test incorporates the key physiological variables needed for independent functioning among older adults. The SFT has been found reliable and it has been validated (Rikli and Jones 1999, 2013). We showed that adult physical performance is predicted by a large number of factors across the life course including adult lifestyle factors such as physical activity and smoking. By far, the

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Table 3 Regression coefficients for the prediction of the overall Rikli-Jones test result (expressed as a z score) using measures of size early in life (expressed as a z score) in models with different sets of covariates included (each measure of size is analyzed separately)

Age (years)	Model 1			Model 2			Model 3			Model 4		
	b	95 % CI	*p*	*b*	95 % CI	*p*	*b*	95 % CI	*p*	*b*	95 % CI	*p*
Length/height												
0	0.089	0.027 to 0.150	0.005	0.080	0.021 to 0.140	0.008	0.067	0.009 to 0.126	0.025	0.063	0.006 to 0.121	0.031
1	0.043	−0.017 to 0.104	0.157	0.024	−0.034 to 0.083	0.412	0.010	−0.047 to 0.068	0.725	0.017	−0.048 to 0.082	0.609
2	0.058	−0.002 to 0.118	0.058	0.035	−0.023 to 0.093	0.236	0.022	−0.035 to 0.079	0.453	0.026	−0.043 to 0.094	0.462
7	−0.021	−0.083 to 0.041	0.511	−0.038	−0.098 to 0.022	0.210	−0.047	−0.106 to 0.012	0.119	−0.136	−0.217 to −0.055	0.001
11	−0.039	−0.101 to 0.023	0.216	−0.052	−0.112 to 0.008	0.088	−0.054	−0.113 to 0.005	0.073	−0.124	−0.201 to −0.046	0.002
Weight												
0	0.076	0.015 to 0.136	0.014	0.078	0.020 to 0.135	0.008	0.061	0.004 to 0.118	0.035	0.067	0.012 to 0.123	0.017
1	0.050	−0.010 to 0.111	0.100	0.041	−0.017 to 0.099	0.162	0.022	−0.035 to 0.079	0.452	0.041	−0.016 to 0.099	0.158
2	0.043	−0.017 to 0.103	0.163	0.036	−0.023 to 0.094	0.230	0.017	−0.041 to 0.075	0.565	0.024	−0.035 to 0.084	0.426
7	−0.028	−0.090 to 0.035	0.387	−0.038	−0.099 to 0.022	0.218	−0.050	−0.110 to 0.010	0.100	−0.046	−0.111 to 0.019	0.163
11	−0.076	−0.138 to −0.013	0.017	−0.081	−0.141 to −0.021	0.008	−0.084	−0.143 to −0.025	0.005	−0.061	−0.123 to 0.002	0.058
Body mass index												
0	0.053	−0.008 to 0.113	0.090	0.066	0.008 to 0.124	0.025	0.050	−0.007 to 0.107	0.088	0.057	0.002 to 0.112	0.041
1	0.035	−0.025 to 0.095	0.255	0.042	−0.015 to 0.100	0.151	0.030	−0.027 to 0.086	0.307	0.044	−0.011 to 0.099	0.114
2	0.008	−0.052 to 0.069	0.784	0.022	−0.036 to 0.079	0.466	0.009	−0.048 to 0.067	0.746	0.019	−0.036 to 0.075	0.494
7	−0.024	−0.086 to 0.038	0.446	−0.021	−0.082 to 0.039	0.483	−0.032	−0.091 to 0.028	0.294	0.014	−0.045 to 0.072	0.646
11	−0.081	−0.143 to −0.018	0.011	−0.075	−0.135 to −0.015	0.014	−0.079	−0.138 to −0.021	0.008	−0.017	−0.075 to 0.042	0.578

Model 1: adjusted for age and sex. Model 2: further adjusted for occupation, education, and adult lifestyle variables. Model 3: further adjusted for metabolic measurements. Model 4: further adjusted for adult anthropometry

b regression coefficient, *CI* confidence interval, *p* *p* value

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Table 4 Regression coefficients for the prediction of the Rikli-Jones components (expressed as *z* scores) using measures of size early in life (expressed as a *z* score) with model 4 adjustments (each measure of size is analyzed separately)

Age (years)	Chair stands			Arm curls			Chair sit and reaches			Distance walked in 6 min			Back scratch		
	b	95 % CI	*p*	*b*	95 % CI	*p*	*b*	95 % CI	*p*	*b*	95 % CI	*p*	*b*	95 % CI	*p*
Length/height															
0	0.021	−0.039 to 0.080	0.496	0.078	0.017 to 0.140	0.013	0.071	0.010 to 0.132	0.022	0.028	−0.025 to 0.081	0.298	0.012	−0.046 to 0.071	0.677
1	−0.003	−0.070 to 0.065	0.941	0.031	−0.039 to 0.101	0.382	0.017	−0.052 to 0.085	0.630	−0.019	−0.079 to 0.041	0.536	0.014	−0.052 to 0.079	0.678
2	−0.001	−0.072 to .070	0.976	0.026	−0.048 to 0.099	0.493	0.048	−0.024 to .120	0.194	−0.007	−0.070 to 0.056	0.824	0.002	−0.067 to 0.071	0.949
7	−0.145	−0.229 to −0.061	0.001	−0.073	−0.161 to 0.014	0.100	−0.104	−0.190 to −0.019	0.017	−0.078	−0.153 to −0.002	0.043	−0.076	−0.158 to 0.006	0.068
11	−0.120	−0.200 to −0.039	0.004	−0.034	−0.117 to 0.049	0.423	−0.098	−0.178 to −0.017	0.018	−0.111	−0.183 to −0.039	0.002	−0.082	−0.160 to −0.003	0.041
Weight															
0	0.030	−0.028 to 0.087	0.310	0.049	−0.011 to 0.108	0.109	0.061	0.003 to 0.120	0.040	0.048	−0.003 to 0.099	0.065	0.041	−0.015 to 0.097	0.152
1	0.009	−0.050 to 0.069	0.762	0.043	−0.019 to 0.105	0.175	0.009	−0.052 to 0.070	0.767	0.048	−0.004 to 0.101	0.073	0.011	−0.047 to 0.070	0.703
2	−0.014	−0.076 to 0.048	0.655	0.027	−0.037 to 0.091	0.406	0.017	−0.046 to 0.080	0.591	0.053	−0.002 to 0.108	0.059	−0.020	−0.080 to 0.041	0.522
7	−0.092	−0.159 to −0.024	0.008	−0.022	−0.092 to 0.048	0.535	−0.041	−0.110 to 0.027	0.235	0.024	−0.036 to 0.084	0.439	−0.031	−0.097 to 0.034	0.349
11	−0.080	−0.145 to −0.016	0.015	−0.014	−0.081 to 0.053	0.682	−0.064	−0.130 to 0.001	0.053	−0.037	−0.095 to 0.021	0.209	−0.021	−0.085 to 0.042	0.508
Body mass index															
0	0.031	−0.025 to 0.088	0.277	0.020	−0.039 to 0.078	0.507	0.040	−0.017 to 0.098	0.170	0.049	−0.001 to 0.099	0.055	0.062	0.007 to 0.117	0.028
1	0.018	−0.038 to 0.075	0.525	0.050	−0.009 to 0.109	0.095	−0.006	−0.064 to 0.052	0.845	0.073	0.023 to 0.124	0.004	0.008	−0.048 to 0.063	0.783
2	−0.012	−0.069 to 0.046	0.684	0.033	−0.027 to 0.092	0.278	−0.017	−0.076 to 0.041	0.564	0.067	0.016 to 0.118	0.010	−0.014	−0.070 to 0.042	0.635
7	−0.034	−0.094 to 0.027	0.273	0.014	−0.049 to 0.077	0.664	−0.001	−0.062 to 0.060	0.977	0.068	0.014 to 0.122	0.014	0.003	−0.056 to 0.062	0.924
11	−0.044	−0.105 to 0.016	0.150	0.003	−0.060 to 0.065	0.934	−0.038	−0.099 to 0.022	0.216	0.009	−0.045 to 0.062	0.754	0.007	−0.052 to 0.066	0.809

Model 4: adjusted for sex, age, occupation, education and adult lifestyle variables, metabolic measurements, and adult anthropometry

b regression coefficient, *CI* confidence interval, *p p* value strongest predictor of physical performance was adult adiposity showing that the higher the body fat percentage, the lower the level of physical performance in old age. Adiposity has also been associated with physical performance in previous studies and is a known factor affecting several adult health outcomes (Bray 2004; Buchan et al. 2012).

The physical performance of the cohort members in the present study was slightly below average for this age group. This difference was most evident in the chair stands test where the average results have been reported to be 14 for men and 13 for women in previous studies (Rikli and Jones 1999, 2013b). The results in our study were on average 12 for men and 11 for women, respectively. In the other physical fitness tests, the participants' performances were within the expected range or above (Rikli and Jones 2013; Wilkin and Haddock 2010). However, participating in the clinical examinations and performing the SFT required a certain level of physical fitness and independence, thus excluding cohort members with severe functional limitations.

We also tested the associations between clinical characteristics and the individual components of the SFT. The heterogeneity of the predictors of physical performance suggests that it is a result of multidimensional exposures, which the individual faces across the life course. Our findings suggest that both biological and psychosocial factors influence physical performance in old age. Physical activity, smoking, educational attainment, and glycemia were all independent predictors of physical performance. We observed that body size at birth, a marker of experiences during prenatal life, was an independent predictor of physical performance 70 years later. The fact that we identified the relationship between body size early in life and physical performance is of importance given the lifetime of multiple exposures and the prevalence of various diseases and conditions which all are known to contribute to physical performance in old age. Prenatal and childhood growth have been shown to be associated with cognition and educational attainment, glucose metabolism, and physical activity (Barker et al. 1989, 1993, 2005; Rich-Edwards et al. 1999; Ben-Shlomo and Kuh 2002; Räikkönen et al. 2007; von Bonsdorff et al. 2011; Power et al. 2013; Hanson and Gluckman 2014; von Bonsdorff et al. 2015; Stewart et al. 2015). Thus, the importance of prenatal and childhood growth might be bigger than the statistical analyses would suggest. Our findings suggest that some aging effects may be traced back to events early in life but also more proximal factors are important. These findings strongly advocate that a holistic view is needed in order to gain more insight into the aging process.

We suggest that the observed association between early growth and physical performance is one example of early programming of health and disease which seems to extend into old age. From a public health point of view, our findings are important and support the importance of focusing upon the health of young women of childbearing age. Further, a small body size at birth has previously been identified as a determinant of several chronic NCDs; now we have also shown that it is associated with poorer physical performance in old age.

We have previously shown that body size birth and childhood growth are associated with physical functioning at an average age of 60 years (von Bonsdorff et al. 2011). The mechanisms through which prenatal growth is linked to physical performance in old age are not well known. One of the underlying reasons might be the suboptimal prenatal environment, reflected in small body size at birth, which may impair organ and tissue development leading to changes in body composition in later life (Ylihärsilä et al. 2007, 2008). Babies who are born thinner have less muscle tissue (Ylihärsilä et al. 2007). Lower birth weight correlates with lower adult lean body mass (Ylihärsilä et al. 2008) and muscle strength in later life (Ylihärsilä et al. 2007; Kuh et al. 2006). Lower birth weight increases the incidence of chronic diseases such as type 2 diabetes, coronary heart disease, and stroke (Barker et al. 1989, 1993, 2005; Rich-Edwards et al. 1999; Ben-Shlomo and Kuh 2002; Eriksson et al. 2006; Osmond et al. 2007; Räikkönen et al. 2007; Hanson and Gluckman 2014), which further increase the prevalence of disability in old age.

This study has several strengths including the use of a large well-characterized study population consisting of both men and women. Further, a long follow-up time provides an opportunity to study predictors of physical performance from a true life course perspective. A further strength is that we measured objectively the overall physical performance instead of single components of fitness. The SFT battery has been validated and developed to measure especially older adults' physical capacity which is needed to perform normal everyday

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activities (Rikli and Jones 1999, 2013). Further, the SFT provides detailed information needed for evaluating specific physical functions, such as aerobic endurance and flexibility.

The findings of this study should be interpreted with some caution. First, even though we were able to take into account a wide range of potential confounders, including adult physical activity, educational attainment, and smoking, we cannot exclude the possibility of residual confounding or effect modifications by potential unmeasured covariates. Those individuals who participated in the clinical examination in 2011–2013 were younger, thinner, more educated, and had a healthier diet in 2001–2004 compared with those who did not participate in the follow-up. Therefore, participants may not be fully representative of all older people living in Helsinki. These restrictions, however, rather undermine than increase our ability to detect statistically significant associations between early growth and overall physical performance in old age. Lastly, our study population included Caucasians only, which might limit generalizability of our results to other ethnic groups.

In conclusion, our study indicates that prenatal growth is one factor predicting physical performance in elderly men and women. Our results suggest that physical performance in older age originates partly in early life and support the importance of focusing upon health and disease from a life course perspective.

Compliance with ethical standards

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