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Original Article

Fruit and vegetable consumption and muscle strength and power during adolescence: a cross-sectional analysis of the Northern Ireland Young Hearts Project 1999-2001

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Abstract

Objectives: To examine the association between fruit and vegetable (FV) consumption and muscle strength and power in an adolescent population. **Methods:** We conducted a cross-sectional analysis among 1019 boys and 998 girls, aged 12 and 15 years, who participated in The Young Hearts Project. FV consumption (excluding potatoes) was assessed by 7-d diet history. Grip strength and jump power was assessed with a dynamometer and Jump-MD meter, respectively. Associations between FV consumption and strength and power were assessed by regression modelling. **Results:** Boys and girls with the highest FV intakes (>237.71 g/d and >267.57 g/d, respectively, based on the highest tertile) had significantly higher jump power than those with the lowest intakes (<135.09 g/d and <147.43 g/d, respectively), after adjustment for confounding factors. Although girls with the highest FV intakes had higher grip strength than those with the lowest intakes, no significant independent associations were evident between FV intake and grip strength in boys or girls. Similar findings were observed when FV were analysed separately. **Conclusions:** Higher FV consumption in this group of adolescents was positively associated with muscle power. There was no independent association between higher FV consumption and muscle strength. Intervention studies are required to determine whether muscle strength and power can be improved through increased FV consumption.

Keywords: Fruit and Vegetables, Muscle Strength, Muscle Power, Adolescents

List of abbreviations

FV	Fruit and Vegetables
YH	Young Hearts
BMD	Bone Mineral Density
BMC	Bone Mineral Content

The authors have no conflict of interest.

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Background

Adolescence is a dynamic period of growth and development, characterised by marked changes in body size, muscle strength and power, and bone mass. Increasing evidence suggests that muscle strength and power are important determinants of bone mass and strength[1,2]. Previous studies of adolescents have reported positive relationships between muscle strength and/or power and bone mineral density (BMD) or bone mineral content (BMC)[3,4]. In a previous analysis of the Young Hearts (YH) study data we also found an association between poor muscle strength and increased fracture risk in children[5]. Poor muscle strength has also been associated with increased risk of sports injuries in children[6].

Dietary intake, particularly during adolescence, is critical for muscle strength and development[7]. However, much of the evidence to date in this age group has focused on the role of nutrient intake on the skeletal system[8-10] rather than the muscular system. Since adolescence represents a period of rapid bone and muscle mass accumulation, a clearer understanding of the role of diet in muscle strength during this period is required. Dietary and other lifestyle influences acting during childhood can have a lifelong impact on muscle mass, muscle strength and future fracture risk[11]. More specifically, accumulating observational evidence suggests that fruit and vegetable (FV) intake and/or intakes of nutrients associated with a FV-rich diet, such as carotenoids may be associated with improved physical function and/or muscle strength[12-15]. However, to our knowledge, all of the studies to date have been conducted in older adults. No population-based studies have examined the relationship between FV consumption and muscle strength and power during the adolescent period.

Although the exact mechanism through which FV may influence muscle strength is not yet clear, it may be related to their high antioxidant content offering protection against oxidative stress and inflammation[13,14], their alkaline salt content which may act as a buffer against excess acid[16] and the presence of nitrates in FV which may improve muscle contraction[17,18].

Based on the current low consumption of FV in adolescence[19], the limited research to date regarding the association between FV consumption and muscle function, and the fact that the evidence focuses on older adults, the aim of the current study was to examine the relationship between habitual FV consumption and objective measures of muscle strength and power in a large, representative population of adolescents.

Methods

Study design

The results from this study are based on data collected as part of the YH2000 study. YH2000 is the second in a series of large cross-sectional epidemiological studies carried out in Northern Irish adolescents. The study design has been described elsewhere[20]. In brief, 3147 boys and girls aged 12 and 15 years were randomly selected from 36 post-primary schools in Northern Ireland between 1999 and 2001. The chosen schools were stratified according to education area board and school selection policy (i.e. grammar and non-grammar schools). From each stratum, a two-stage cluster sample of children was obtained, with the probability of selection proportional to the size of the school. Of the 3147 boys and girls randomly selected from the schools, 2017 (1019 boys, 998 girls) gave consent to participate. Ethical approval was obtained from the Research Ethics Committee of Queen's University Belfast, and written informed consent obtained from all participants and their parents or guardians prior to participation. All participants were seen at school and the data was collected on one occasion, during normal school hours and during the normal academic year for post-primary schools in Northern Ireland (i.e. September – June).

Dietary intake assessment

Dietary data were obtained using a nutritionist-administered 7-day diet history. This involved an open-ended one-to-one interview to ascertain the habitual food intake of each participant and more specifically to assess FV intake. Participants verbally recalled their weekly food intake by reporting the frequency, amounts and methods of preparation of foods consumed. In relation to FV intake, participants reported whether FV were fresh, frozen, tinned, dried or pureed. Amounts of foods were reported as household measures (e.g. 1 tablespoon) or natural measures (e.g. 1 slice). A photographic food atlas of known portion sizes and standard UK Food Portion Sizes[21] were also used to quantify intakes. Following completion of the diet history, all food amounts were converted into g. Energy and nutrient intakes were calculated using a computerized food analysis database based on UK food composition tables (WISP, Tinuviel Software, Warrington, UK). A food file was also created from the food analysis database which included a record of all foods consumed by each participant and corresponding weights. From this, individual foods and weights were condensed and categorised into food groups and total fruit intake and total vegetable intake (both g/day) were calculated. One portion of fruit or vegetables is normally considered to be 80 g (for an adult)[22] although this varies according to country and type of fruit or vegetable. In the UK, a child's portion of FV is based on a handful of FV rather than a weight[22]. Foods were defined as a fruit or vegetable according to Department of Health guidelines[22], with vegetable-based soups included in vegetable intake, fruit juices included in fruit intake and potatoes excluded from vegetable intake. Supplement use was assessed in a separate self-report questionnaire and was not included in the dietary intake analyses.

Assessment of muscle strength and power

Isometric grip strength was assessed using a hand-held dynamometer (Takei Scientific Instruments Limited, Japan). Each participant was asked to stand with their arms held straight by their sides and to grip the handle of the dynamometer as hard as possible for three seconds, without body contact and without flexion of the elbow. Measurements (in kg force) were repeated twice with each arm, with the highest of the recorded measurements being used in analyses. Maximal vertical jump power was measured using a Jump-MD meter (Takei Scientific Instruments Limited, Japan). Each participant stood in the centre of the test mat with the display unit attached around their waist. The participant performed a counter movement jump, as high as possible, with free arm movement and landing with two feet on the mat. The best of two attempts (in cms) was recorded.

Anthropometry and lifestyle measurements

Height was measured to the nearest millimeter using a stadiometer (Holtain Ltd, Crymych, Dyfed), weight was measured to the nearest 0.1kg using calibrated electronic scales (Seca Ltd, Hamburg). For both measurements, participants wore light indoor clothing and no shoes. BMI was calculated as weight (kg) divided by height (m) squared and BMI-for-age z-scores were derived for each participant using the World Health Organisation growth reference software[23]. Pubertal status of each participant was assessed by a paediatrician on the basis of visual indicators including non-genital secondary hair growth, vocal

	Boys (n_{max}=1006)	Girls (n_{max}=995)	*p* value[b]
12 year olds n (%)	525 (52%)	513 (52%)	0.78
15 year olds n (%)	481 (48%)	482 (48%)	0.78
Height (cm)	1.62 (0.12)	1.58 (0.78)	<0.001
Weight (kg)	52.91 (13.63)	53.04 (11.50)	0.82
BMI (kg/m^2)	19.98 (3.41)	21.11 (3.63)	<0.001
BMI z-score	0.19 (1.12)	0.40 (1.02)	< 0.001
Grip strength (kg)	26.87 (9.06)	21.48 (5.08)	<0.001
Vertical jump performance (cm)	44.17 (8.44)	37.13 (6.09)	<0.001
Physical activity score[c]	29.97 (15.64)	20.56 (13.55)	<0.001
Self-reported alcohol consumer n (%)			
Yes	223 (22%)	175 (18%)	0.01
No	780 (78%)	816 (82%)	
Energy intake (kcal/d)	2991.15 (907.81)	2435.16 (768.05)	<0.001
EAR[d] 11-14 year olds (kcal/d)	2220	1845	
EAR[d] 15-18 year olds (kcal/d)	2755	2110	
Protein intake (g/d)	82.79 (22.61)	67.94 (18.25)	<0.001
RNI[e] 11-14 year olds (g/d)	42.1	41.2	
RNI[e] 15-18 year olds (g/d)	55.2	45.0	
Calcium intake (mg/d)	1069.83 (400.66)	862.58 (327.48)	<0.001
RNI[e] 11-14 year olds (mg/d)	1000	800	
RNI[e] 15-18 year olds (mg/d)	1000	800	
Fruit intake[f] (g/d)	143.71 (145.03)	166.14 (154.97)	0.001
Vegetable intake[g] (g/d)	72.33 (58.34)	72.23 (53.17)	0.97
Fruit and vegetable intake (g/d)	216.04 (156.48)	238.37 (169.96)	<0.01
UK recommendations (adult) (g/d)[h]	400 g/d	400 g/d	

[a] Values are n (%) or mean (SD).
[b] *p* value for difference between boys and girls (independent samples t-test)
[c] Highest possible activity score=100
[d] Estimated average requirement[30]
[e] Reference nutrient intake[30]
[f] Fruit intake included fruit juices
[g] Vegetable intake included vegetable-based soups and excluded potatoes
[h] UK Department of Health FV recommendations for adults[22]

Table 1. Descriptive characteristics of the study population[a].

timbre, body habitus, muscular development[24]. A self-report questionnaire was used to obtain demographic information. Socio-economic status was based upon the current or usual occupation of the head of the household, and classified according to the Office of Population Censuses and Surveys[25]. Physical activity (PA) was assessed using a self-administered 7-day recall questionnaire which estimated activity from routine events including travel to and from school, school breaks, afterschool activities, and PA during evenings and weekends[26]. Each PA was scored and a total PA score out of 100 calculated.

Statistical analyses

Statistical analyses were performed using SPSS (version 17; SPSS Inc., Chicago, US). Descriptive statistics were obtained for each variable of interest according to sex. Continuous variables were normally distributed and summarised using mean (SD). Gender comparisons were made using independent samples t-tests and chi-square analysis for continuous and categorical variables respectively. Bivariate correlation analyses were conducted to examine the direction and magnitude of relationships between grip strength and other explanatory variables. Sex-specific linear regression analyses were then undertaken to examine associations between tertiles of FV intake and grip strength. Fruit intake and vegetable intake were examined separately, as well as together, as other studies[27-29], including a previous analysis of YH data[8], found differing associations for fruit versus vegetables and other health outcomes. Fruit intakes, vegetable intakes and combined FV intakes were grouped separately into tertiles using dummy variables, allowing comparisons to be made between tertile 3 and tertile 2 and be-

Categories	Grip strength (kg)				Vertical jump performance (cm)			
	Boys		Girls		Boys		Girls	
	Difference in mean (95% CI)	*p* value	Difference in mean (95% CI)	*p* value	Difference in mean (95% CI)	*p* value	Difference in mean (95% CI)	*p* value
Model 1								
Tertile 3 (highest intake)[a]	Reference		Reference		Reference		Reference	
Tertile 2	-1.01 (-2.39,0.36)	0.15	-0.89 (-1.66,-0.11)	0.02	-1.02 (-2.33,0.28)	0.12	-0.83 (-1.77,0.12)	0.09
Tertile 1 (lowest intake)	0.42 (-0.96,1.81)	0.55	-0.92 (-1.70,-0.14)	0.02	-0.75 (-2.06,0.57)	0.26	-1.16 (-2.10,-0.21)	0.02
Model 2								
Tertile 3 (highest intake)[a]	Reference		Reference		Reference		Reference	
Tertile 2	-0.39 (-1.12,0.35)	0.30	-0.55 (-1.14,0.04)	0.07	-0.85 (-1.91,0.21)	0.11	-0.74 (-1.67,0.19)	0.12
Tertile 1 (lowest intake)	-0.57 (-1.31,0.17)	0.13	-1.19 (-1.78,-0.60)	<0.001	-1.39 (-2.46,-0.33)	0.01	-1.22 (-2.16,-0.29)	0.01
Model 3								
Tertile 3 (highest intake)[a]	Reference		Reference		Reference		Reference	
Tertile 2	-0.32 (-1.06, 0.42)	0.39	-0.36 (-0.94,0.23)	0.24	-0.72 (-1.78,0.33)	0.18	-0.46 (-1.38,0.46)	0.33
Tertile 1 (lowest intake)	-0.43 (-1.18,0.31)	0.26	-0.84 (-1.44,-0.24)	<0.01	-1.09 (-2.16,-0.02)	0.05	-0.67 (-1.61,0.27)	0.16
Model 4								
Tertile 3 (highest intake)[a]	Reference		Reference		Reference		Reference	
Tertile 2	-0.30 (-1.10,0.50)	0.46	-0.11 (-0.75,0.54)	0.74	-0.41 (-1.54,0.71)	0.47	-0.47 (-1.48,0.54)	0.36
Tertile 1 (lowest intake)	-0.30 (-1.12,0..53)	0.48	-0.75 (-1.41,-0.09)	0.02	-1.15 (-2.30,0.01)	0.05	-0.53 (-1.57, 0.51)	0.32

[a] Reference category used in linear regression analysis. For boys, tertile 1 (lowest fruit intake) was defined as <65.57 g/d, tertile 2 (moderate fruit intake) as 65.57 – 154.86 g/d, tertile 3 (highest fruit intake) as >154.86 g/d. For girls, tertile 1 (lowest fruit intake) was defined as <83.48 g/d, tertile 2 (moderate fruit intake) as 83.48 – 185.95 g/d, tertile 3 (highest fruit intake) as >185.95 g/d.

Model 1: unadjusted; Model 2: adjusted for age, BMI z-score, pubertal status, energy intake; Model 3: adjusted for model 2 variables and physical activity; Model 4: adjusted for model 3 variables and socio-economic status

Table 2. Relationship between fruit intake and grip strength and jump performance in boys and girls.

tween tertile 3 and tertile 1. The following cut-offs were used to define tertile 1, tertile 2 and tertile 3 of fruit intake: <65.57 g/d, 65.57-154.86 g/d and >154.86 g/d in boys, respectively, and <83.48 g/d, 83.48-185.95 g/d and >185.95 g/d in girls, respectively. Tertiles 1, 2 and 3 of vegetable intake were defined as <42.86 g/d, 42.86-82.86 g/d and >82.86 g/d in boys, respectively, and <45.28 g/d, 45.28-81.95 g/d and >81.95 g/d in girls, respectively. Tertiles 1, 2 and 3 of total FV intake were defined as <135.09 g/d, 135.09-237.71 g/d and >237.71 g/d in boys, respectively, and <147.43 g/d, 147.43-267.57 g/d and >267.57 g/d in girls, respectively. In all analyses, tertile 3 was set as the reference group. A one-way ANOVA was used to determine differences between the tertiles of FV consumption. Sex-specific univariate models were constructed with grip strength as the dependent variable and the tertiles of fruit intake, the tertiles of vegetable intake or the tertiles of total FV intake as the explanatory variable. Multivariate linear regression models were constructed with adjustment for potential confounders. Model 1 was unadjusted; model 2 was adjusted for age, BMI z-score, pubertal status and energy intake (EI); model 3 was adjusted for model 2 variables and PA; model 4 was adjusted for model 3 variables and socio-economic status. To test for a linear trend, an additional analysis was performed using fruit intake, vegetable intake and total FV intake as continuous variables in the models rather than categorical variables. All analyses were repeated using jump power as the dependent variable. Participants for whom there was no grip strength or jump power measurement were excluded from respective analyses. Significance level was set as p<0.05.

Results

General characteristics

From a total of 2017 participants, grip strength data was available for 2001 (99%) participants (1006 boys, 995 girls) and vertical jump data for 1917 (95%) participants (956 boys, 961 girls). Table 1 summarizes the physical characteristics of the study population according to sex.

Participants were aged 12 (52% of boys, 52% of girls) and 15 years (48% of boys, 48% of girls). Mean grip strength was 26.87 kg (SD 9.06) and 21.48 kg (SD 5.08) for boys and girls respectively, while maximal vertical jump performance was 44.17 cm (SD 8.44) and 37.13 cm (SD 6.09) respectively. Boys were taller, more physically active and had greater jump power and grip strength compared to girls (all *p*<0.001). They also had higher intakes of energy, protein and calcium (all *p*<0.001) compared to girls. More boys reported consuming alcohol compared to girls (p=0.01). Girls had a higher BMI z-score than boys (p<0.001) and also had higher fruit intake than boys (*p*=0.001). Self-reported mean daily intakes of energy, protein

	Grip strength (kg)				**Vertical jump performance (cm)**			
	Boys		**Girls**		**Boys**		**Girls**	
Categories	Difference in mean (95% CI)	*p* value	Difference in mean (95% CI)	*p* value	Difference in mean (95% CI)	*p* value	Difference in mean (95% CI)	*p* value
Model 1								
Tertile 3 (highest intake)[a]	Reference		Reference		Reference		Reference	
Tertile 2	-0.94 (-2.33,0.46)	0.19	-0.66 (-1.44,0.12)	0.10	-0.15 (-1.47,1.16)	0.82	-1.04 (-1.99,-0.09)	0.03
Tertile 1 (lowest intake)	-1.13 (-2.53,0.26)	0.11	-0.36 (-1.14,0.42)	0.37	-0.49 (-1.81,0.83)	0.47	-1.22 (-2.17,-0.28)	0.01
Model 2								
Tertile 3 (highest intake)[a]	Reference		Reference		Reference		Reference	
Tertile 2	-0.18 (-0.93,0.57)	0.63	-0.43 (-1.03,0.16)	0.16	0.32 (-0.75,1.40)	0.56	-0.79 (-1.73,0.15)	0.10
Tertile 1 (lowest intake)	0.30 (-0.45,1.04)	0.44	-0.40 (-0.99,0.19)	0.18	0.51 (-0.57,1.59)	0.35	-1.15 (-2.08,-0.22)	0.02
Model 3								
Tertile 3 (highest intake)[a]	Reference		Reference		Reference		Reference	
Tertile 2	-0.25 (-0.99,0.50)	0.52	-0.36 (-0.95,0.22)	0.23	0.19 (-0.88,1.26)	0.73	-0.73 (-1.65,0.20)	0.12
Tertile 1 (lowest intake)	0.34 (-0.41,1.08)	0.38	-0.25 (-0.84,0.33)	0.40	0.55 (-0.53,1.62)	0.32	-0.95 (-1.87,-0.04)	0.04
Model 4								
Tertile 3 (highest intake)[a]	Reference		Reference		Reference		Reference	
Tertile 2	-0.30 (-1.13,0.53)	0.47	-0.47 (-1.11,0.17)	0.15	0.36 (-0.80,1.51)	0.54	-0.85 (-1.86,0.16)	0.10
Tertile 1 (lowest intake)	0.11 (-0.71,0.93)	0.80	-0.03 (-0.67,0.62)	0.94	0.54 (-0.60,1.69)	0.35	-0.94 (-1.94,0.07)	0.07

[a] Reference category used in linear regression analysis. For boys, tertile 1 (lowest vegetable intake) was defined as <42.86 g/d, tertile 2 (moderate vegetable intake) as 42.86-82.86 g/d, tertile 3 (highest vegetable intake) as >82.86 g/d. For girls, tertile 1 (lowest vegetable intake) was defined as <45.28 g/d, tertile 2 (moderate vegetable intake) as 45.28-81.95 g/d, tertile 3 (highest vegetable intake) as >81.95 g/d.

Model 1: unadjusted; Model 2: adjusted for age, BMI z-score, pubertal status, energy intake; Model 3: adjusted for model 2 variables and physical activity; Model 4: adjusted for model 3 variables and socio-economic status

Table 3. Relationship between vegetable intake and grip strength and jump performance in boys and girls.

and calcium were higher than UK dietary reference values for both boys and girls[30].

Results of a one-way ANOVA based on tertiles of total FV intake revealed that there were significant differences in physical characteristics of participants between tertiles (data not shown). Participants in the highest FV tertile were taller (p=0.01), more physically active (p<0.001), and had higher intakes of energy (p=0.04), protein (p<0.001) and calcium (p<0.001) than those in the other tertiles (data not shown). There were also a lower proportion of alcohol consumers in the highest FV tertile compared to the other tertiles (p<0.001, chi-square test).

Regression analyses

The relationships between tertiles of fruit intake and grip strength or jump power are shown in Table 2. In the unadjusted model (model 1), girls with the highest fruit intakes had higher grip strength and jump power than girls with the lowest fruit intakes (both *p*=0.02). Girls with the highest fruit intakes also had higher grip strength than those with moderate intakes (*p*=0.02). After adjusting for age, BMI z-score, pubertal status and EI (model 2), the association between the highest (*versus* lowest) fruit intake and grip strength and jump power in girls remained significant (*p*<0.01 and *p*=0.01, respectively). Boys with the highest fruit intake had higher jump power than boys with the lowest fruit intake after adjusting for age, BMI z-score, pubertal status and EI (*p*=0.01). Further adjustment for PA (model 3) resulted in loss of significance between fruit intake and jump power in both boys and girls but did not affect the association between fruit intake and grip strength in girls. The significant association between fruit intake and grip strength in girls also remained after further adjustment for socio-economic status (p=0.02). No significant associations were evident between grip strength and fruit intake in boys.

The adjusted and unadjusted relationships between tertiles of vegetable intake and grip strength or jump power are shown in Table 3. No significant associations were evident between tertiles of vegetable intake and grip strength in boys or girls and there was no association between tertiles of vegetable intake and jump power in boys. In the unadjusted analyses (model 1), girls with the highest vegetable intakes had significantly higher jump power than girls with low (*p*=0.01) or moderate (*p*=0.03) vegetable intakes. The association between jump power and the high *versus* low vegetable intake category in girls remained significant, after further adjustment for age, BMI z-score, pubertal status, EI and PA (p=0.04, model 3) but significance was lost after adjustment for socio-economic status (model 4).

A further analysis was carried out to examine the association between tertiles of total FV intake and grip strength and jump

Categories	Grip strength (kg)				Vertical jump performance (cm)			
	Boys		Girls		Boys		Girls	
	Difference in mean (95% CI)	*p* value	Difference in mean (95% CI)	*p* value	Difference in mean (95% CI)	*p* value	Difference in mean (95% CI)	*p* value
Model 1								
Tertile 3 (highest intake)[a]	Reference		Reference		Reference		Reference	
Tertile 2	-1.56 (-2.94,-0.18)	0.03	-0.63 (-1.41,0.14)	0.11	-1.21 (-2.51,0.10)	0.07	-1.14 (-2.08,-0.19)	0.02
Tertile 1 (lowest intake)	-0.58 (-1.96,0.80)	0.41	-0.99 (-1.77,-0.22)	0.01	-1.80 (-3.10,-0.49)	<0.01	-1.66 (-2.61,-0.72)	<0.01
Model 2								
Tertile 3 (highest intake)[a]	Reference		Reference		Reference		Reference	
Tertile 2	-0.18 (-0.92, 0.56)	0.63	-0.48 (-1.07, 0.12)	0.12	-0.51 (-1.58,0.56)	0.35	-1.04 (-1.97,0.11)	0.03
Tertile 1 (lowest intake)	-0.24 (-0.98,0.49)	0.52	-1.09 (-1.68,-0.50)	<0.001	-1.58 (-2.64,-0.52)	<0.01	-1.70 (-2.63,-0.77)	<0.001
Model 3								
Tertile 3 (highest intake)[a]	Reference		Reference		Reference		Reference	
Tertile 2	-0.11 (-0.85,0.64)	0.78	-0.31 (-0.90,0.28)	0.30	-0.38 (-1.44,0.68)	0.48	-0.84 (-1.76,0.08)	0.07
Tertile 1 (lowest intake)	-0.11 (-0.85,0.63)	0.77	-0.75 (-1.35,-0.15)	0.01	-1.40 (-2.37,-0.24)	0.02	-1.20 (-2.14,-0.27)	0.01
Model 4								
Tertile 3 (highest intake)[a]	Reference		Reference		Reference		Reference	
Tertile 2	0.08 (-0.73,0.90)	0.84	-0.01 (-0.65,0.63)	0.96	-0.47 (-1.60,0.66)	0.42	-0.86 (-1.66,0.34)	0.20
Tertile 1 (lowest intake)	0.03 (-0.78,0.85)	0.94	-0.51 (-1.18,0.16)	0.13	-1.27 (-2.41,-0.13)	0.03	1.08 (-2.12,-0.03)	0.04

[a] Reference category used in linear regression analysis. For boys, tertile 1 (lowest FV intake) was defined as <135.09 g/d, tertile 2 (moderate FV intake) as 135.09 – 237.71 g/d, tertile 3 (highest FV intake) as >237.71 g/d. For girls, tertile 1 (lowest FV intake) was defined as <147.43 g/d, tertile 2 (moderate FV intake) as 147.43 - 267.57 g/d, tertile 3 (highest FV intake) as >267.57 g/d.

Model 1: unadjusted; Model 2: adjusted for age, BMI z-score, pubertal status, energy intake; Model 3: adjusted for model 2 variables and physical activity; Model 4: adjusted for model 3 variables and socio-economic status

Table 4. Relationship between total FV intake and grip strength and jump performance in boys and girls.

power (Table 4). In the unadjusted model (model 1), boys with the highest total FV intake had significantly higher grip strength than boys with a moderate FV intake (p=0.03), however significance was lost after adjusting for confounding factors. Girls with the highest total FV intake had significantly higher grip strength than girls with the lowest FV intake (p=0.01), even after adjustment for age, BMI z-score, pubertal status, EI and PA. However, significance was lost after inclusion of socio-economic status (model 4). In relation to jump power, boys with the highest total FV intake had significantly higher jump power than those with the lowest intakes, even after adjustment for potential confounding factors. In girls, those with the highest intakes of total FV were shown to have higher jump power than girls with the lowest or moderate intakes. Significance remained in the highest *versus* lowest intake category after adjustment for confounding factors (model 4, p=0.04). The results became attenuated for the moderate *versus* lowest intake category after inclusion of PA (model 3, p=0.11) and socio-economic status (model 4, p=0.20).

When the analyses were repeated, using fruit or vegetables as continuous variables rather than categorical, a positive association was observed between fruit intake and grip strength in girls after adjusting for age, BMI z-score, pubertal status, EI and PA (p<0.01). A positive association was also observed between fruit intake and jump power in girls after adjusting for age, BMI z-score, pubertal status and EI (p<0.01). These analyses showed that an increase in fruit consumption of 80 g (1 portion) was associated with a 0.16 kg increase in grip strength and a 0.24 cm increase in jump power in girls. However, significance was lost for both jump power and grip strength after further adjustment for PA and socio-economic status, respectively. Fruit intake was positively associated with jump power in boys after adjusting for age, BMI z-score, pubertal status and EI (p=0.04) but significance was lost after further adjustment for PA. No significant associations were observed between fruit intake and grip strength in boys and no significant associations were observed between vegetable intake and grip strength in boys or girls. Vegetable intake was positively associated with jump power in girls after adjusting for all potential covariates (p=0.01) but no significant associations were evident in boys. Similarly, total FV intake showed no association with grip strength or jump power in boys, in contrast to girls where the association remained significant with jump power after further adjustment for PA (p=0.02) and with grip strength after adjustment for socio-economic status (p=0.04) (data not shown).

Discussion

To our knowledge, this is the first population-based study to investigate the association between FV intake and muscle strength and power during adolescence. In this group of adolescents, we showed that in girls, but not boys, higher vegetable consumption was significantly associated with jump power relative to the lowest levels of consumption, after adjusting for confounding factors including PA, although significance was lost after further adjustment for socio-economic status. Higher fruit consumption was also significantly associated with jump power in both boys and girls although significance was lost after adjusting for PA. In relation to muscle strength, no significant associations were evident between vegetable intake and grip strength in either girls or boys. Higher fruit consumption was significantly associated with grip strength in girls, but not boys, even after additional adjustment for PA and socio-economic status. Examining overall FV intake appeared to strengthen the relationship with jump power in both boys and girls, with the association remaining significant after adjustment for confounding factors. In fact, the findings suggest that in this population higher total FV intake was an independent predictor of jump power, in both boys and girls.

The associations between fruit intake and muscle function appeared to be somewhat stronger in girls than boys, particularly in relation to grip strength. Alongside this, daily fruit intake was significantly higher in girls than in boys. This is in contrast to the findings from the National Diet and Nutrition Survey where fruit intake was higher in boys than girls[31]. It is possible that in this population, fruit consumption in boys was at an insufficient level to show a strong association with grip strength. Alternatively, boys had higher PA scores than girls, which may have weakened the relationship between fruit intake and grip strength. There may be a threshold effect for PA, which boys are more likely to exceed, and are therefore able to consume less FV without it affecting their muscle strength. Boys may also undertake more weight-bearing or high intensity PA than girls which in turn may have a greater influence on muscle strength[32]. The gender differences observed may also reflect inherent physiological differences in muscle structure[33-35]. Indeed, previous studies have suggested that gender-specific differences in muscle are due to hormonal changes during puberty[34,36], although, in the current study, we adjusted for pubertal status. Furthermore, it is possible that it is a combined effect of both a healthy diet and PA that results in greater muscle strength. However, these suggestions are mostly hypothetical and require further exploration.

Comparing our results with other studies is difficult as there is limited evidence regarding the association between FV intake and muscle strength and power, and any research to date has focused on older populations. Nevertheless, our findings do lend support to those reported elsewhere. Previous cross-sectional studies conducted in older adults showed that poor muscle strength was associated with low serum carotenoid levels[12,14], thus reflecting low FV intake. A population-based study reported a positive correlation between plasma antioxidant concentrations and measures of physical performance and muscle strength[14]. Other studies have reported similar associations between nutrients commonly found in FV, and measures of muscle strength and physical function[12,13,37].

Although the mechanism responsible for the association between FV intake and muscle strength remains obscure, our findings are nonetheless biologically plausible. Indeed, it has been suggested that FV may act on muscle in three ways: 1) their antioxidant effect[13,14], 2) their anti-inflammatory effect[13,14], and, 3) their alkaline forming properties which act as a buffer against oxidative stress and inflammation[16,37]. Another potential mechanism, which requires further investigation, is the possible influence of nitrates present within FV which may improve muscle contraction[17,18].

Important strengths of this study include its large representative sample of healthy adolescents from Northern Ireland. Unlike previous studies which relied on food frequency questionnaire to assess FV consumption, the current study used a relatively robust and validated method[38] for assessing FV consumption, which has previously shown good validity at estimating EI at the group level in adolescents[39]. A further strength is that muscle strength and power were assessed by direct performance-based measures rather than self-report questionnaires. Handgrip strength is considered to be a valid indicator of general muscle strength[40], while vertical jump power is a valuable index of muscular power[41]. Examining muscle strength and power in this age group also seemed prudent, since it is during adolescence that the greatest gains in peak bone mass and muscle strength are achieved[3,42]. Handgrip strength is also an independent predictor of BMC and bone area of the total body and/or forearm in adolescent girls[3] and in a previous analysis of YH2000 data we showed that muscle strength was a modulator of fracture risk in children[5].

Several limitations of the study merit consideration. The cross-sectional design means that we cannot draw causal conclusions from the findings. Further cross-sectional and prospective cohort studies are needed to confirm the observed relationships. A further limitation, in common with all observational studies, is the possibility of residual confounding or failure to include other potential confounders. However, the extensive range of data collected enabled us to adjust for important covariates. Despite using a rigorous dietary assessment method, we also cannot rule out possible under- or over-reporting of dietary intake and more specifically FV intake. Indeed, while the reported mean daily intakes of energy, protein and calcium are higher than UK dietary reference values, the reported intakes are relatively similar to those reported in the recent UK-based National Diet and Nutrition Survey[31]. In addition, it is possible that FV present within some composite dishes were not accounted for, although where possible such dishes were separated into their individual ingredients, thus enabling a more accurate estimation of FV content. These dietary assessment limitations, however, may have attenuated the strength of any observed associations. Dietary intake assessment at one timepoint may also be inadequate to fully capture true FV intake and may not be representative of changes in FV intakes over a year. The handgrip values for participants in the present study are also slightly lower than those reported in other UK[43] and European populations[44] although this may reflect methodological differences such as variations in the type of dynamometers, or variations in protocols for measuring grip strength. A further limitation of the current study is that FV intakes in this population group were below the UK government recommendations of 5 portions of FV/d (based on 1 portion=80 g)[22]. It is therefore possible that the results observed may not extrapolate to benefits beyond meeting the recommendations. However, it is difficult to gauge this for children since 80 g is considered an adult portion[22]. For children, the current UK recommendations are given as handfuls and not weights i.e. one portion of fruit or vegetables is the amount that a child can fit into the palm of their hand[22]. FV portion sizes also vary according to country and the type of fruit or vegetable. For these reasons, we presented the data as weights of FV intake rather than portions of FV.

Conclusions

This study has shown that in adolescence, higher FV intake is positively associated with muscle power. There was no independent association observed between higher FV consumption and muscle strength. Examining FV separately also revealed that in girls, but not boys, higher vegetable consumption was associated with muscle power relative to lower consumption levels. Higher fruit consumption was also associated with muscle power in both boys and girls and with muscle strength in girls, but the associations with muscle power became non-significant when adjusted for PA. The inconsistency observed between boys and girls highlights a need for further gender-specific research to be carried out in adolescents. Further observational and, ideally, intervention studies, are also needed to more clearly define the complex nature of the associations. Overall, the findings of this study are important, particularly since optimising muscle power, which in itself is a product of both muscle strength and speed[45,46], is considered to be fundamental for enhancing performance in many sporting activities that are carried out during youth[47,48] and also for maintaining physical function in later life[49]. Based on the low FV consumption in the current study, the findings highlight a need for public health strategies to focus on ways of increasing FV consumption during adolescence as a potential means of improving muscle power.

Authors' information

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