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ABSTRACT

Purpose. To examine the associations of birth weight with ability in school sports in adolescence and participation in leisure-time physical activity (LTPA) across adulthood, and to investigate whether associations between birth weight and LTPA change with age. **Methods.** Study participants were British singletons born in 1946 and followed-up to age 68 (the MRC National Survey of Health and Development). Birth weights were extracted from birth records. Teacher reports of ability in school sports were collected at age 13 years. LTPA was self-reported at ages 36, 43, 53, 60-64 and 68 years and categorised at each age as participating in sports, exercise and other vigorous LTPA at least once per month versus no participation. Associations were examined using standard and mixed-effects logistic regression models. **Results.** Relevant data were available for 2,739 study participants (50.1% female). When compared with the low birth weight group (≤2.50 kg), those with heavier birth weights were more likely to be rated as above average or average at school sports (vs below average); fully-adjusted odds ratio (OR) =1.78 (95% confidence interval (CI): 1.14–2.77). Across adulthood, those with heavier birth weights were more likely to participate in LTPA than those with low birth weight; fully-adjusted OR of LTPA across adulthood=1.52 (95% CI: 1.09–2.14). This association did not vary by age (p=0.5 for birth weight by age interaction). **Conclusions.** Low birth weight was associated with lower ability in school sports and with nonparticipation in LTPA across adulthood. Identifying the underlying developmental and social processes operating across life for low birth weight infants may inform the design of appropriate interventions to support participation in LTPA across life.

KEY WORDS: Birth weight; Life course; Exercise; Sports; Physical activity

INTRODUCTION

Regular leisure-time physical activity (LTPA) provides many health benefits that include reduced rates of early death from chronic disease while in contrast physical inactivity is a major contributor to morbidity and premature mortality (2, 39). In order to develop interventions which are more effective at promoting LTPA, a better understanding of its determinants from across life is required (6, 10, 13, 19). Studies taking a life course approach suggest that biological and social factors in early life may influence adult health-related behaviours including LTPA (3, 6, 7, 10, 13, 19, 20, 29, 30). These include studies that have examined hypothesised associations between size at birth (as a marker of exposures in utero) and physical activity across different phases of life (1, 3, 18, 26, 28, 30, 31, 33).

The foetal origins of adult disease hypothesis (5) suggests that in utero experiences such as under-nutrition can, in addition to limiting size at birth, alter development and increase susceptibility to chronic disease. Lower birth weight has been associated with higher risks of cardiovascular disease (5, 38) and type II diabetes (41), and more recently also with lower aerobic fitness and muscular endurance (32) and less favourable body composition in terms of lower bone (23) and muscle mass (4), and weaker muscle strength (12). Low birth weight has also been associated with poorer motor and cognitive development (27).

These findings (4, 5, 12, 23, 27, 32, 38, 41) alongside animal studies showing less physical activity in those born to undernourished mothers (42) provide evidence to suggest that adolescents and adults with low birth weight might participate less in LTPA. The underlying mechanisms may operate through an impact on the motor skills required to develop competence at sports, a reduced exercise capacity and subsequent self-selection out of sports and exercise in those born with low birth weight (11, 13). Moreover, an impaired exercise capacity is also a

reported consequence of reduced gestational age (i.e. preterm birth) (11, 13) and thus any associations between low birth weight and less LTPA could be driven by intrauterine growth restriction, a reduced gestational age, or a combination of both.

Of the existing epidemiological studies that have investigated associations between birth weight and physical activity, inconsistent results are reported with a tendency to find null associations (26, 28, 29, 31) or less LTPA in those born with low birth weight (1, 3, 18, 33). Most studies have examined activity in childhood, adolescence or young adulthood and/or rely on a single measure of physical activity. However, the influence of birth weight on chronic disease risk is more apparent later in life (38, 41) so it could be that associations with LTPA might also be more apparent in adulthood. Thus studies which extend into and across adulthood are required. In addition, assessment of whether any associations found change across adult life may help establish underlying mechanisms which could have important implications for future intervention. Therefore, the aim of this study was to examine the associations of birth weight with ability in school sports in adolescence and participation in LTPA across adulthood, and to investigate whether the association between birth weight and LTPA changes with age.

METHODS

Study population

Study participants were from the Medical Research Council (MRC) National Survey of Health and Development (NSHD), a nationally representative sample of 5,362 British singleton births during one week in March 1946 and followed up regularly across childhood and adulthood (21). At age 13 (1959) the school teacher who was most familiar with each study participant completed a school-based questionnaire. At ages 36 (1982), 43 (1989) and 53 (1999) trained

nurses interviewed and assessed the study participants in their own homes. At age 60-64 (2006-2010) they attended one of 6 clinical research facilities or received a home visit and at age 68 (2014) they completed a postal questionnaire.

Of those successfully contacted at ages 36 (n=3,322), 43 (n=3,262), 53 (n=3035), 60-64 (n=2,661) and 68 years (n=2,453), 99.6%, 100%, 98.4%, 82.2% and 99.1% respectively provided information on LTPA (3,766 participants had at least one measure of LTPA). The participating samples at ages 53 and 60-64 have been found to be broadly representative of similar aged members of the general UK population (34, 37). At the last completed round of data collection at age 68 years, 83.4% of 2,943 study participants who were still alive and eligible to participate were successfully contacted. Of the 490 who were not successfully contacted, 11 had died, 453 did not return a questionnaire and 26 questionnaires were returned undelivered.

Relevant ethics approval has been granted for each data collection; ethical approval for the most recent assessment in 2014 was obtained from the Queen Square Research Ethics Committee (14/LO/1073) and the Scotland A Research Ethics Committee (14/SS/1009). Study participants provided written informed consent.

Measurements

Birth weight

Birth weight, recorded to the nearest quarter of a pound, was extracted from birth records within 6 weeks of delivery and subsequently converted to kg.

School sports ability and adulthood LTPA

When study participants were 13 years old, teachers were asked to complete a questionnaire rating their ability in school sports as above average, average or below average compared with their peers (20). This measure is used as a marker of study participants' overall ability at school-based games and activities requiring competence in motor skills and coordination (e.g. team sports, physical education, athletics), and was previously shown to relate to LTPA at age 36 (20). At ages 36, 43, 53, 60-64 and 68 years, study participants reported how often they participated in LTPA during nurse interviews or using self-completed questionnaires. At age 36, study participants reported the number of times they took part in 27 different sports, exercises and other leisure activities during the previous month using questions based on the Minnesota LTPA questionnaire (20). At age 43, information was collected on participation in sports, exercise or other vigorous leisure activities in the previous year including for how many months and how often in those months activities were performed (9). At age 53, study participants were asked how often they participated in sports, exercise or other vigorous leisure activities during the previous four weeks and this question was asked again at ages 60-64 and 68. At each age, study participants were classed as inactive if they reported no participation in LTPA, moderately active if they participated up to four times in LTPA or regularly active if they reported taking part five or more times in LTPA (in the previous month at age 36, per month at age 43, and in the previous 4 weeks at ages 53, 60-64 and 68).

Covariates

Birth order, childhood socioeconomic position and cognitive ability were identified as potential confounders based on existing literature (6, 14, 24). Based on mother's report of birth order, study participants were classified as first, second, or third or later born. Father's Registrar

General's occupational class at age 4 years was used to indicate socioeconomic position in childhood and was grouped into four categories (I&II: professional, managerial or technical, IIINM: skilled non-manual, IIIM: skilled manual and IV&V: partly skilled or unskilled). Cognitive ability was tested at age 8 years in a school setting and included vocabulary, comprehension and reading tests from which a standardised cognitive score was derived. Missing paternal occupational class (n=173) and cognition scores (n=199) were imputed with values recorded at ages 11 and 15 years.

In addition to the above covariates, sports ability in childhood and physical health in adulthood were hypothesised to mediate associations between birth weight and adulthood LTPA. Physical health was derived from information collected during nurse interviews at age 36 years on weight, disability, self-reported health problems, hypertension, lung function and incidence of hospital admissions (22). This information was used to categorise participants into worst, intermediate or best physical health (22). Supplementary analyses in those with information on body mass index (BMI) were also carried out in order to examine whether body size mediated associations. BMI (kg/m^2) was derived from height and weight measured using standardised protocols in childhood at age 11 and in adulthood at age 36.

Statistical Analysis

Formal tests of interactions between sex and birth weight were undertaken and subsequent analyses were adjusted for sex after no evidence of interaction was found. Formal tests of deviation from linearity were performed and showed evidence of non-linear associations between birth weight and sports ability and LTPA. As a result, study participants were grouped into five categories of birth weight (≤ 2.50 kg, 2.51-3.00 kg, 3.01-3.50 kg, 3.51-4.00 kg and > 4.00 kg) and the low birth weight group (≤ 2.50 kg) was used as the reference in analyses. For

the purpose of these analyses, dichotomous measures of sports ability and LTPA were derived. The two groups of above average and average ability in school sports were combined and compared to the group with below-average ability. At each age in adulthood, the two groups reporting moderate and regular participation in LTPA were combined and compared to the group that reported no participation in LTPA.

We examined how birth weight relates to ability in school sports using logistic regression. The association between birth weight and LTPA across adulthood was examined using mixed-effects binary logistic regression with random intercepts and slopes for age so that we could include all participants with at least one measure of LTPA whilst also accounting for correlations among repeated LTPA responses (25). In all models we included sex and a sex by age interaction. In order to investigate whether the association between birth weight and probability of being active in LTPA changes with increasing age we added a birth weight by age interaction term to the mixed-effects models. The estimated fixed-effects coefficients were used to plot the log-odds of LTPA for each birth weight group against age. In addition, multinomial mixed-effects models (25) estimated using a simulation approach were fit to the categorical LTPA data in order to examine the associations of birth weight with moderate and regular participation in LTPA (see Table, Supplementary Digital Content 1, Associations between birth weight and moderate and regular participation in leisure-time physical activity, http://links.lww.com/MSS/A745).

Models of the associations of birth weight with both sports ability and LTPA were first adjusted for sex and then for birth order, socioeconomic position and cognitive ability. An additional model was then run when examining the association between birth weight and LTPA which included adjustment for ability in school sports and physical health in adulthood. Lastly, we reran both final models in those with data on BMI and compared estimates to models with added

adjustment for BMI. Sports ability models were adjusted for childhood BMI while LTPA models were adjusted for adult BMI. Analyses were carried out in STATA 14 (StataCorp, Texas).

RESULTS

Characteristics of study participants

A total of 2,739 study participants had at least one measure of adulthood LTPA and complete data on ability in school sports, birth weight and all selected covariates (Table 1). The majority of included participants had LTPA data from four of the five different ages in adulthood (a total of 10,980 LTPA assessments between ages 36 and 68 were included in analyses). When compared with those excluded due to missing LTPA data (n=1,596), higher proportions of those with at least one measure of LTPA were female (49.6% vs. 42.5%) and had fathers in occupational classes I & II (23.1% v 20.9%) and lower proportions had low birth weight (4.7% vs. 8.8%). At age 13 years, higher proportions of girls were rated as above average or average in school sports (Table 1). At ages 36 and 43 years, higher proportions of men reported taking part in LTPA but sex-differences were less marked at older ages (Table 1).

Birth weight and ability in school sports at age 13 years

When compared with the low birth weight group (≤ 2.50 kg), those in other heavier birth weight categories were more likely to be rated as above average or average (vs below average) at school sports at age 13 years (Table 2). For example, the sex-adjusted OR of above average or average sports ability was 1.89 (95%CI: 1.22–2.93) when combining the four other birth weight groups and comparing this larger group with the low birth weight group. This association was only slightly attenuated when models were adjusted for birth order, cognitive ability and socioeconomic position (Table 2) (fully-adjusted OR of above average or average sports ability =

1.78; 95%CI: 1.14–2.77, when comparing those in all heavier birth weight groups with the low birth weight group). Further adjustment for childhood BMI slightly strengthened this association (see Table S2A, Supplementary Digital Content 2, Associations between birth weight and ability in school sports at 13 years and participation in leisure-time physical activity, http://links.lww.com/MSS/A746).

Birth weight and leisure-time physical activity between ages 36–68 years

When compared with the low birth weight group, those in all heavier birth weight groups were more likely to participate in LTPA across adulthood (Table 2). There was no evidence of an interaction between birth weight and age (p=0.5 for continuous and categorical birth weight by age interactions) suggesting these associations did not differ by age at assessment of LTPA. This is consistent with the finding of similar ORs of LTPA at each age in adulthood in study participants with non-missing LTPA (see Table, Supplementary Digital Content 3, Associations between birth weight and leisure-time physical activity at each adult age in study participants, http://links.lww.com/MSS/A747). A plot of the log-odds of LTPA shows the decline in likelihood of activity with age for all five birth weight groups with the lowest birth weight group always having lower probability of LTPA (Figure 1). This plot also shows that while men were more likely to report LTPA earlier in adulthood, women had less pronounced decline in LTPA across adulthood in all birth weight groups (Figure 1).

The association between birth weight and LTPA was slightly attenuated by adjustment for early life covariates and to a lesser degree by further adjustment for ability in school sports and physical health in adulthood (Table 2). The sex-adjusted OR of adulthood LTPA was 1.92 (95%CI: 1.35–2.73) when comparing those in the group combining the four heavier birth weight groups with the low birth weight group, which was attenuated to 1.63 (95%CI: 1.16–2.29)

following adjustment for early life covariates, and to 1.52 (95%CI: 1.09–2.14) in the fully-adjusted model. Associations between low birth weight and lower likelihood of participation in LTPA were stronger with more frequent participation (see Table, Supplementary Digital Content 1, Associations between birth weight and moderate and regular participation in leisure-time physical activity, http://links.lww.com/MSS/A745). The sex-adjusted relative risk ratios (95% CI) of moderate (1-4 times per month) and regular (5 or more times per month) LTPA across adulthood (vs. no participation) were 1.60 (1.24–2.12) and 2.83 (1.87–4.37) respectively when comparing all four heavier birth weight groups with the low birth weight group. These estimates were attenuated to 1.25 (0.90–1.93) and 1.81 (1.23–2.57) respectively after full adjustment. Additional adjustment for adulthood BMI had little influence on findings (see Table S2B, Supplementary Digital Content 2, Associations between birth weight and ability in school sports at 13 years and participation in leisure-time physical activity, http://links.lww.com/MSS/A746).

DISCUSSION

We examined prospectively collected data from the longest running British birth cohort and found that low birth weight was associated with lower ability in school sports and with nonparticipation in LTPA across adulthood. More precisely, our findings showed that, when compared with low birth weight, those in heavier birth weight groups were more likely to be rated by their school teacher as above average or average rather than below average in sports at age 13 and were more likely to participate in LTPA between ages 36 and 68 years. These associations were only partly attenuated after adjustment for a range of covariates.

Comparison with other studies

Some of the other studies which have previously investigated this association in younger more recently born cohorts support our findings (1, 3, 18). These include a meta-analysis which showed Scandinavian adolescents and adults in lower birth weight groups (range=1.26 to 2.75 kg) were less likely to participate in LTPA than the reference birth weight group (3.26–3.75 kg) (1), and higher levels of leisure-time physical inactivity reported by 23-year old Brazilian women born in 1982 with low birth weight (<2.50 kg) (3). Also supporting our results are findings of less participation in outdoor sporting activity by 12-year old Australian adolescents with low birth weight (<2.00 kg) that persisted over 5-years follow-up (18).

We found that associations between low birth weight and lower likelihood of LTPA were consistent across adult life which is similar to animal studies showing offspring from undernourished mothers to be less physically active across life, including at older adult ages, when compared with normal offspring (42). That associations between birth weight and LTPA were apparent at older ages is similar to findings from a Finnish study showing older adults with an average age of 62 years reported higher intensity LTPA if they were bigger at birth in terms of weight and length (33).

The results presented here are not consistent with null-associations reported between birth weight and physical activity levels in children (26, 28). However, as associations between birth weight and chronic disease tend to be more apparent later in life (38, 41) this may also be the case for LTPA (1, 3, 18, 33). Likewise, it is also thought that associations between preterm birth and LTPA tend to be more apparent in adulthood and adolescence than in childhood (11). Our findings are also in contrast to a study from the next oldest British birth cohort born in 1958

where the authors reported that no differences were found between low (<2.50 kg) and heavier birth weights in levels of LTPA assessed in mid-adulthood but no estimate was provided (30).

Explanation of findings

Our findings suggest that prenatal growth may influence sports ability and participation in LTPA across life (8, 13). Motor deficits including difficulties in movement-related tasks and other neurocognitive impairments have been reported in children with low birth weight (27), which may explain the associations found here with lower ability in school sports. A lower sports ability in early life has also been shown to be associated with less LTPA in adulthood (20, 29, 30) however, adjustment for sports ability only marginally reduced the association between birth weight and adulthood LTPA; thus other pathways besides tracking of physical activity into adulthood are likely involved in explaining that finding.

Poorer levels of motor skills and coordination (27), less favourable body composition (4, 23) including weaker muscle strength (12) and more prevalent chronic disease (5, 38, 41) in those with low birth weight may contribute to their higher probability of nonparticipation in LTPA across adulthood. Yet, the associations found in this study between birth weight and LTPA were consistent across adulthood which suggests that health conditions related to birth weight may not play a major role in explaining these findings. Consistent with this, adjusting for adult physical health problems only slightly weakened the association between birth weight and LTPA.

Methodological considerations

There was some loss to follow-up in NSHD, as expected in long-running studies. This led to only slight differences in characteristics between those included and those with missing data. A survival selection bias where those healthiest and physically active from the low birth weight group survive to an older age is possible and may have biased results towards the null. However,

our modelling strategy maximises sample size and improves precision of estimates of association as all individuals with at least one measure of LTPA are included under the missing at random assumption (25). Other important strengths of this study included the collection of measured birth weights from birth records within weeks of delivery, adjustment for important and prospectively ascertained covariates and an investigation of age-related changes in associations with LTPA. In addition, we were also able to examine the relationship between birth weights and an indicator of sports ability from early life and to compare findings with those of participation in LTPA across adulthood.

One limitation of this study is that information on gestational age was not available and therefore we could not distinguish between those born small-for-gestational age and those with low birth weight due to preterm birth. However, there would have been less variation in gestational age in this study population than in more recent born cohorts as preterm births were less likely to survive in the 1940s (36). As a result of reduced survival, there were a limited number of participants classified as having low birth weight in our study but despite reduced statistical power, associations were observed with both outcomes. In addition, birth weight is the only measure of birth size available in NSHD and is only a proxy marker of the adaptations that a foetus may make to its body's structure and function in response to stress experienced in utero.

Self-reported LTPA can be subject to recall and misclassification errors therefore, a cautious interpretation of the findings is necessary. However, questionnaires/interviews help capture contextual circumstances surrounding physical activity making them suitable for widespread gathering of data on activity types and domains like LTPA (35). If there was differential reporting of LTPA by birth weight groups this could bias our findings however, we have no reason to suspect this to be the case. Furthermore, when self-reported physical activity and data

from activity monitors were compared in a subsample of this cohort they were found to rank study participants similarly by levels of physical activity (15). Those participating in LTPA across adulthood were also found to spend greater amounts of time in moderate-to-vigorous intensity activity as assessed by these monitors when compared with others reporting no LTPA (17). The LTPA measures used here were relatively crude in that they summarised activity according to whether or not any participation in LTPA was reported. However, even small amounts of LTPA are important for health particularly in older populations (2, 39). Further, in supplementary analyses we were able to show a dose-response nature to this association suggesting those with low birth weights were even less likely to report higher levels of LTPA across adulthood.

Implications

It is important to recognise that those with low birth weight may require more support than others if they are to achieve sufficient physical activity across life to realise its health benefits (2, 16, 39). The associations observed are likely to be generalisable to more recently born cohorts since associations have been seen in the same direction in younger cohorts (1, 3, 18). The increasing long-term survival rates of babies born with low birth weight (36, 40) means that there are increasing numbers of adults who were born with low birth weight and thus there may be a growing proportion of the population who are at greater risk of having lower competence at sports and who are unlikely to be participating in LTPA. Designing appropriate interventions may require a better understanding of how related processes like postnatal growth, motor capability and body composition influence physical activity in those with low birth weight. Furthermore, in order to allow more meaningful comparison of findings between different cohorts, it would be useful to harmonise methods of analyses.

In conclusion, findings from this 68-year prospective follow-up study of the 1946 British birth cohort showed that, when compared with those with low birth weight, other study participants with heavier birth weights were less likely to be rated by their school teacher as below average at sports and were more likely to participate in LTPA across adulthood. Understanding the underlying biological, developmental and social processes that explain the relationship between low birth weight and low sports ability and nonparticipation in LTPA may help identify appropriate characteristics of effective interventions.

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Data used in this publication are available to bona fide researchers upon request to the NSHD Data Sharing Committee via a standard application procedure. Further details can be found at http://www.nshd.mrc.ac.uk/data. doi: 10.5522/NSHD/Q101; doi: 10.5522/NSHD/Q102; doi: 10.5522/NSHD/Q103.

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We have no competing interests to declare.

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The results of the present study do not constitute endorsement by the American College of Sports Medicine.

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Figure Legend

Figure 1 Log-odds of leisure-time physical activity for each birth weight group by age in the MRC National Survey of Health and Development.

Footnote: Plots presented separately for men and women because of a sex by age interaction which means that the decline in LTPA is greater in men than women.

Table Legend

Table 1 Characteristics of study participants with relevant data from the MRC National Survey of Health and Development overall and by sex (n=2,739).

Table 2 Associations between birth weight and ability in school sports at 13 years and participation in leisure-time physical activity (LTPA) between 36–68 years in the MRC National Survey of Health and Development (n=2,739).

Supplementary Digital Content 1.pdf Associations between birth weight and moderate and regular participation in leisure-time physical activity (LTPA) between ages 36–68 years in the MRC National Survey of Health and Development (n=2,739).

Supplementary Digital Content 2.pdf Associations between birth weight and ability in school sports at 13 years and participation in leisure-time physical activity between 36–68 years after additional adjustment for body mass index (BMI).

Supplementary Digital Content 3.pdf Associations between birth weight and leisure-time physical activity at each adult age in study participants with no missing data.

Figure 1

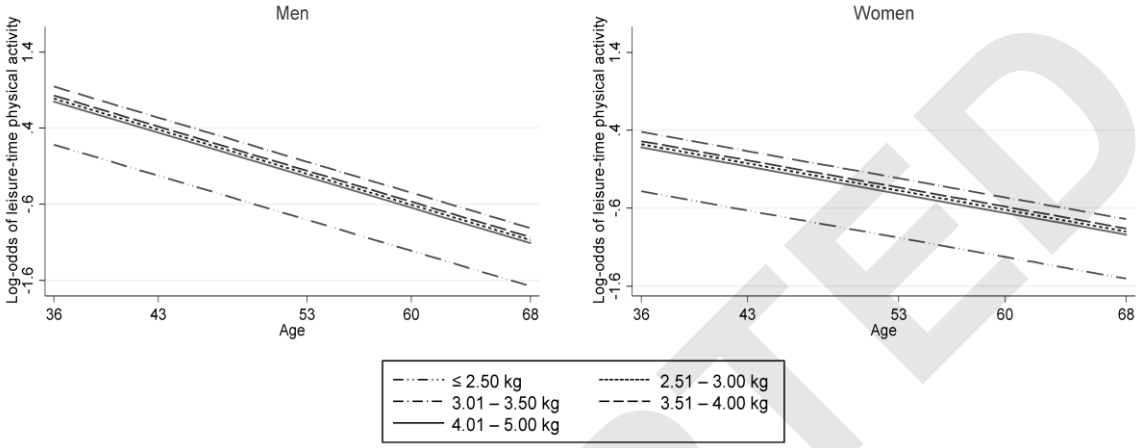

Table 1 Characteristics of study participants with relevant data from the MRC National Survey of Health and Development overall and by sex (n=2,739).

	Overall N (%)	Males N (%)	Females N (%)	p-value of sex-difference test
Birth weight (kg)				p<0.001
≤ 2.50	120 (4.4)	42 (3.1)	78 (5.7)	
2.51-3.00	455 (16.6)	180 (13.2)	275 (20.0)	
3.01-3.50	974 (35.6)	466 (34.1)	508 (37.0)	
3.51-4.00	906 (33.1)	488 (35.7)	418 (30.5)	
> 4.00	284 (10.4)	191 (14.0)	93 (6.8)	
Ability in school sports age 13				p=0.001
above average or average ability	2327 (85.0)	1130 (82.7)	1197 (87.2)	
below average ability	412 (15.0)	237 (17.3)	175 (12.8)	
Leisure-time physical activity across adulthood[a]				
age 36	1725 (63.0)	941 (68.9)	784 (57.2)	p<0.001
age 43	1165 (47.0)	635 (51.2)	530 (42.9)	p<0.001
age 53	1134 (50.5)	568 (52.0)	566 (49.1)	p=0.2
age 60-64	606 (35.6)	277 (33.7)	329 (37.4)	p=0.1
age 68	725 (39.9)	345 (39.9)	380 (39.8)	p=0.9
Birth order				p=0.7
first born	1129 (41.2)	569 (41.6)	560 (40.8)	

second born	905 (33.0)	441 (32.3)	464 (33.8)	
third or later born	705 (25.7)	357 (26.1)	348 (25.4)	
Father's occupational class age 4				p=0.9
professional/managerial/technical	601 (22.0)	300 (22.0)	301 (22.0)	
skilled non-manual	503 (18.4)	246 (18.0)	257 (18.7)	
skilled manual	842 (30.7)	416 (30.4)	426 (31.1)	
partly skilled or unskilled	793 (29.0)	405 (29.6)	388 (28.3)	
Cognitive ability age 8[b]	2739 (100)	-0.01 (0.8)	0.04 (0.8)	p=0.1
Physical health age 36				p=0.7
worst	710 (25.9)	356 (26.0)	354 (25.8)	
intermediate	1748 (63.8)	864 (63.2)	884 (64.4)	
best	281 (10.3)	147 (10.8)	134 (9.8)	

≤ 2.50 kg: range = 1.25 – 2.50 kg (mean=2.30 kg). > 4.00 kg: range = 4.09 – 5.00 kg (mean=4.32 kg). [a]Proportions are for those taking part (once or more than once per month) in leisure-time physical activity at each age. [b]Data shows mean (standard deviation) standardised cognitive ability z-score (overall mean=0; overall standard deviation=1).

Table 2 Associations between birth weight and ability in school sports at 13 years and participation in leisure-time physical activity (LTPA) between 36–68 years in the MRC National Survey of Health and Development (n=2,739).

	OR (95% CI) of above average or average ability in sports versus below average ability		OR (95% CI) of LTPA (at least once per month) across adulthood versus no LTPA		
	Model 1	Model 2	Model 1	Model 2	Model 3
Birth weight group (kg)					
≤ 2.50	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
2.51-3.00	1.97 (1.19 – 3.25)	1.91 (1.15 – 3.16)	1.74 (1.18 – 2.56)	1.50 (1.03 – 2.17)	1.40 (0.97 – 2.03)
3.01-3.50	2.01 (1.26 – 3.19)	1.91 (1.20 – 3.05)	2.14 (1.49 – 3.08)	1.82 (1.28 – 2.59)	1.69 (1.19 – 2.39)
3.51-4.00	1.82 (1.14 – 2.89)	1.66 (1.04 – 2.66)	1.84 (1.27 – 2.65)	1.52 (1.06 – 2.16)	1.43 (1.01 – 2.03)

> 4.00	1.60	1.41	1.74	1.54	1.47
	(0.95 – 2.72)	(0.82 – 2.42)	(1.15 – 2.63)	(1.03 – 2.30)	(0.98 – 2.19)

OR: Odds ratio. 95% CI: 95% confidence intervals. Model 1: adjusted for sex. Model 2: adjusted for sex, birth order, cognitive ability and father's occupational class. Model 3: as for model 2 plus additional adjustment for ability in school sports and physical health in adulthood. ≤ 2.50 kg: range = 1.25 – 2.50 kg (mean=2.30 kg). > 4.00 kg: range = 4.09 – 5.00 kg (mean=4.32 kg).

Supplementary Digital Content 1 Associations between birth weight and moderate and regular participation in leisure-time physical activity (LTPA) between ages 36–68 years in the MRC National Survey of Health and Development (n=2,739).

	RRR (95% CrI) of moderate LTPA (1-4 times per month) versus no LTPA			RRR (95% CrI) of regular LTPA (5 or more times per month) versus no LTPA		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Birth weight (kg)						
≤ 2.50	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
2.51-3.00	1.50 (1.10 – 2.05)	1.31 (0.91 – 1.83)	1.23 (0.86 – 1.75)	2.27 (1.40 – 3.56)	1.85 (1.29 – 2.77)	1.78 (1.16 – 2.55)
3.01-3.50	1.69 (1.29 – 2.23)	1.48 (1.10 – 2.12)	1.35 (1.00 – 1.98)	2.78 (1.91 – 4.00)	2.28 (1.62 – 3.40)	2.06 (1.48 – 2.81)
3.51-4.00	1.45 (1.11 – 1.94)	1.23 (0.92 – 1.73)	1.15 (0.82 – 1.64)	2.57 (1.70 – 3.78)	2.02 (1.41 – 2.80)	1.89 (1.30 – 2.69)
> 4.00	1.34 (0.95 – 1.86)	1.24 (0.84 – 1.76)	1.16 (0.79 – 1.68)	2.35 (1.50 – 3.60)	2.04 (1.33 – 2.99)	1.92 (1.23 – 2.78)

RRR: Relative risk ratio. 95% CrI: 95% Bayesian credible intervals. Model 1: adjusted for sex. Model 2: adjusted for sex, birth order, cognitive ability and father's occupational class. Model 3: as for model 2 plus additional adjustment for ability in school sports and physical health in adulthood. See next page for methods.

Methods

The relative risk ratios of moderate (1-4 times per month) and regular (5 or more times per month) participation in LTPA with those reporting no LTPA as reference group were calculated using mixed-effects multinomial logistic regression models with individually varying intercepts (1, 2). These models were estimated with Markov Chain Monte Carlo (MCMC) simulation (3-5) as implemented in the MLwiN software v2.36 (Centre for Multilevel Modelling, University of Bristol) (4) and analyses were carried out from within STATA using the runmlwin command (5). Parameter estimates from iterative generalised least squares and marginal quasilikelihood estimation models were specified as initial values for the MCMC estimation models. Diffuse (uninformative) prior distributions were used to approximate maximum likelihood estimation and 500 iterations for the burn-in period and 5000 iterations for the monitoring period were specified (4, 5).

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Supplementary Digital Content 2 Associations between birth weight and ability in school sports at 13 years and participation in leisure-time physical activity between 36–68 years after additional adjustment for body mass index (BMI).

Table S2A Birth weight and ability in school sports at 13 years

	OR (95% CI) of above average or average ability in sports versus below average ability	
	Model A	Model B
Birth weight group (kg)		
≤ 2.50 (n=180)	1.00 (reference)	1.00 (reference)
2.51-3.00 (n=657)	1.59 (1.04 – 2.42)	1.63 (1.07 – 2.49)
3.01-3.50 (n=1355)	1.44 (0.98 – 2.13)	1.52 (1.03 – 2.26)
3.51-4.00 (n=1288)	1.51 (1.01 – 2.24)	1.64 (1.10 – 2.44)
> 4.00 (n=431)	1.33 (0.85 – 2.09)	1.50 (0.95 – 2.35)

N=3911 (sample comprises those with data on birth weight, ability in school sports, birth order, cognitive ability, father's occupational class and childhood BMI). Model A: adjusted for sex, birth order, cognitive ability and father's occupational class. Model B: as for model A plus adjustment for BMI at age 11.

Table S2B Birth weight and participation in leisure-time physical activity (LTPA) between 36–68 years

	OR (95% CI) of LTPA (at least once per month) across adulthood versus no LTPA	
	Model A	Model B
Birth weight group (kg)		
≤ 2.50 (n=120)	1.00 (reference)	1.00 (reference)
2.51-3.00 (n=455)	1.39 (0.96 – 2.02)	1.37 (0.95 – 1.98)
3.01-3.50 (n=974)	1.68 (1.19 – 2.39)	1.70 (1.20 – 2.41)
3.51-4.00 (n=906)	1.42 (1.00 – 2.03)	1.47 (1.03 – 2.08)
> 4.00 (n=282)	1.50 (1.00 – 2.23)	1.54 (1.04 – 2.30)

N=2737 (sample comprises those with at least one measure of LTPA and data on birth weight, ability in school sports, birth order, cognitive ability, father's occupational class and adulthood BMI). Model A: adjusted for sex, birth order, cognitive ability, father's occupational class, ability in school sports and physical health in adulthood. Model B: as for model A plus adjustment for BMI at age 36.

Supplementary Digital Content 3 Associations between birth weight and leisure-time physical activity (LTPA) at each adult age in study participants with no missing data

	OR (95% CI) of LTPA (at least once per month) versus no LTPA		
	Model 1	Model 2	Model 3
Birth weight (kg)			
LTPA age 36 years			
≤ 2.50	1.00 (reference)	1.00 (reference)	1.00 (reference)
2.51-3.00	1.71 (0.98 – 2.98)	1.58 (0.89 – 2.79)	1.55 (0.88 – 2.75)
3.01-3.50	2.16 (1.28 – 3.65)	2.00 (1.17 – 3.41)	1.95 (1.14 – 3.33)
3.51-4.00	1.78 (1.05 – 3.01)	1.56 (0.91 – 2.69)	1.54 (0.90 – 2.66)
> 4.00	1.82 (0.996 – 3.34)	1.75 (0.94 – 3.27)	1.71 (0.91 – 3.20)
LTPA age 43 years			
≤ 2.50	1.00 (reference)	1.00 (reference)	1.00 (reference)
2.51-3.00	1.34 (0.76 – 2.37)	1.25 (0.70 – 2.25)	1.23 (0.68 – 2.20)
3.01-3.50	1.96 (1.15 – 3.34)	1.86 (1.08 – 3.22)	1.80 (1.04 – 3.12)
3.51-4.00	1.77 (1.03 – 3.03)	1.63 (0.93 – 2.83)	1.60 (0.92 – 2.80)
> 4.00	1.70 (0.93 – 3.13)	1.83 (0.97 – 3.44)	1.77 (0.94 – 3.33)
LTPA age 53 years			
≤ 2.50	1.00 (reference)	1.00 (reference)	1.00 (reference)
2.51-3.00	1.65 (0.94 – 2.88)	1.48 (0.84 – 2.63)	1.47 (0.83 – 2.62)
3.01-3.50	1.96 (1.16 – 3.31)	1.77 (1.03 – 3.03)	1.73 (1.01 – 2.97)
3.51-4.00	1.96 (1.15 – 3.32)	1.69 (0.98 – 2.91)	1.68 (0.97 – 2.90)
> 4.00	1.45 (0.80 – 2.64)	1.41 (0.76 – 2.63)	1.37 (0.73 – 2.56)
LTPA age 60-64 years			
≤ 2.50	1.00 (reference)	1.00 (reference)	1.00 (reference)
2.51-3.00	2.13 (1.11 – 4.08)	1.94 (0.999 – 3.76)	1.93 (0.99 – 3.77)
3.01-3.50	2.36 (1.27 – 4.38)	2.16 (1.15 – 4.05)	2.12 (1.12 – 4.01)
3.51-4.00	2.43 (1.30 – 4.53)	2.12 (1.12 – 4.01)	2.14 (1.13 – 4.08)
> 4.00	1.94 (0.97 – 3.88)	1.86 (0.91 – 3.79)	1.83 (0.89 – 3.75)
LTPA age 68 years			
≤ 2.50	1.00 (reference)	1.00 (reference)	1.00 (reference)
2.51-3.00	1.61 (0.90 – 2.88)	1.42 (0.78 – 2.58)	1.41 (0.78 – 2.57)
3.01-3.50	1.45 (0.84 – 2.51)	1.26 (0.72 – 2.21)	1.24 (0.71 – 2.18)
3.51-4.00	1.66 (0.96 – 2.88)	1.35 (0.77 – 2.39)	1.36 (0.77 – 2.40)
> 4.00	1.34 (0.72 – 2.51)	1.15 (0.60 – 2.19)	1.13 (0.59 – 2.17)

N=1413 (sample restricted to those with complete data on leisure-time physical activity from each age across adulthood). ≤ 2.50 kg (n=65, range=1.36 to 2.50 kg; mean=2.29 kg), 2.51-3.00 kg (n=228), 3.01-3.50 kg (n=522), 3.51-4.00 kg (n=458), > 4.0 kg (n=140, range=4.09 to 5.00 kg; mean=4.31 kg). OR: Odds Ratio. 95% CI: 95% Confidence Intervals. Model 1: adjusted for sex. Model 2: adjusted for sex, birth order, father's occupational class and cognitive ability. Model 3: as for model 2 plus additional adjustment for ability in school sports and physical health in adulthood. Models at age 60-64 were also adjusted for age.