Original citation:
Kumpulainen, Satu M., Heinonen, Kati, Pesonen, Anu-Katriina, Salonen, Minna K., Andersson, Sture , Lano, Aulikki , Wolke, Dieter, Kajantie, Eero , Eriksson, Johan G. and Raikkonen, Katri . (2017) Childhood cognitive ability and physical activity in young adulthood. Health Psychology, 36 (6). pp. 587-597.

Title Page

Childhood Cognitive Ability and Physical Activity in Young Adulthood

Authors: Satu M Kumpulainen[1], MA, Kati Heinonen[1], PhD, Anu-Katriina Pesonen[1], PhD, Minna K Salonen[2,3], PhD, Sture Andersson[4], MD, DMSc, Aulikki Lano[4], MD, PhD, Dieter Wolke[5], PhD, Eero Kajantie[2,4,6], MD, DMSc, Johan G Eriksson[2,3,7], MD, DMSc, Katri Raikkonen[1,] PhD

Affiliations: [1]Institute of Behavioral Sciences, University of Helsinki, Helsinki, Finland; [2]National Institute for Health and Welfare, Helsinki and Oulu, Finland; [3]Folkhälsan Research Center, Helsinki, Finland; [4]Children's Hospital, University of Helsinki and Helsinki University Hospital, Helsinki, Finland; [5]Department of Psychology, University of Warwick, UK; [6]PEDEGO Research Unit, MRC Oulu, Oulu University Hospital and University of Oulu, Oulu, Finland; [7]Department of General Practice and Primary Health Care, University of Helsinki and Helsinki University Hospital, Helsinki, Finland

Corresponding Author: Satu Kumpulainen, Institute of Behavioral Sciences, P.O. Box 9, 00014 University of Helsinki, Helsinki, Finland; satu.m.kumpulainenhelsinki.fi

tel: +358504160350; fax: +358919129521

Conflict of Interest:

The authors have no competing interest to report.

Abstract

Objective: Childhood cognitive ability is associated with lifestyle in adulthood, including self-reported physical activity (PA). We examined whether childhood cognitive ability is associated with objectively-measured PA and sedentary time (ST) in young adulthood.

Methods: Participants of the Arvo Ylppö Longitudinal Study (n=500) underwent tests of general reasoning, visuo-motor integration, verbal competence and language comprehension at the age of 56 months yielding a general intelligence factor score; at the age of 25 years they wore omnidirectional accelerometers for 9 days (Range=4-10 days) measuring overall daily PA (counts per minute, cpm), ST and light and moderate-to-vigorous PA (MVPA) (minutes), and completed a questionnaire on occupational, commuting, leisure-time conditioning and non-conditioning PA.

Results: After adjustment for sex, age, BMI-for-age SD score at 56 months and mean of valid minutes of measurement period for PA, per each one SD increase in the childhood general intelligence factor score, overall daily PA decreased by -8.99 CPM/day, ST increased by 14.93 minutes/day, time spent in light PA decreased by -14.39 minutes/day, and the odds per each level increase in physical demandingness of the work and in time spent in non-conditioning leisure-time PA decreased by 38% and 31%, respectively (p-values<0.04). These associations were mediated via higher young adulthood level of education.

Conclusions: In contrast to expected, in this cohort of young adults with high variability in PA, of whom many were still studying, higher childhood cognitive ability was associated with more objectively-measured and self-reported physical inactivity. Whether these findings persist beyond young adulthood is a subject of further studies.

Keywords: cognitive ability; physical activity; sedentary time

Introduction

Over 30 percent of the world’s adult population is physically inactive (Hallal et al., 2012). Not surprisingly, physical inactivity is the fourth leading risk factor for mortality worldwide, accounting for 5.5% of all deaths, 3.2 million per year (WHO, 2009). In high-income countries physical inactivity is also the sixth leading risk factor for burden of disease as measured by disability-adjusted life years (DALYS): it accounts for 4.1 percent of DALYs, 5 million per year (WHO, 2009). In cause-specific terms, physical inactivity has been estimated to cause 30% of the disease burden related to cardiovascular disease, 27% related to diabetes, and 21% to 25% related to breast and colon cancer, respectively (WHO, 2009).

It has also become increasingly clear that low levels of moderate-to-vigorous physical activity and high levels of sedentary time (ST), such as sitting, computer use, watching TV, are independent predictors of multiple adverse health outcomes (Thorp, Owen, Neuhaus, & Dunstan, 2011). Apart from policies and programmes to increase physical activity (PA) and decrease ST, there is an urgent need to identify factors as early in life as possible that may underlie individual differences in PA and ST (Rhodes, Mark, & Temmel, 2012).

One such factor may be childhood cognitive ability. During the past decade a series of ‘cognitive epidemiology’ studies have shown that higher childhood cognitive or mental ability is related to reduced risk of obesity (Batty, Deary, & Macintyre, 2007; Belsky et al., 2013; Chandola, Deary, Blane, & Batty, 2006; Corley, Gow, Starr, & Deary, 2010; Gale, Batty, Cooper, & Deary, 2009; Kanazawa, 2013; Kumpulainen et al., 2016; Lawlor, Clark, Davey Smith, & Leon, 2006) and cardiovascular disease (Hart et al., 2004) in adult life.

One mechanism that may explain these associations is that individuals with different cognitive abilities may interpret and respond to health advice differently, and hence engage in health-promoting lifestyle behaviors in different ways (Batty, Deary, Schoon, & Gale, 2007). Indeed, studies have shown that higher childhood cognitive or mental ability is associated with healthier diet (Batty et al., 2007), reduced risk of smoking initiation (Daly & Egan, 2016; Kubicka, Matejcek, Dytrych, & Roth, 2001; Martin, Fitzmaurice, Kindlon, & Buka, 2004), and higher likelihood of smoking cessation (Daly & Egan, 2016; Taylor et al., 2003). While findings with adulthood alcohol consumption are more mixed (Batty et al., 2008; Kubicka et al., 2001; Wennber, Andersson, & Bohman, 2002), there is evidence that higher childhood cognitive or mental ability is associated with an increased odds of being a non-drinker in adulthood (Mortensen, Sorensen, & Gronbaek, 2005), and with a lower likelihood of experiencing alcohol-induced hangovers in midlife (Batty, Deary, & Macintyre, 2006).

Yet, the extent to which childhood cognitive ability is related to PA and ST in adult life remains less well known. We are aware of only three studies that to date have examined the associations between childhood cognitive ability and adulthood PA and ST. In the first study, higher verbal and non-verbal mental ability at the age of 10 years were associated with higher likelihood of taking exercise and exercising more intensively at the age of 30 years (Batty et al., 2007). In the second study higher general intelligence at ages 7, 11 and 16 was associated with exercising more frequently at ages 33, 42, 47, and 51 years (Kanazawa, 2013). Finally, the third study tested if higher PA and its proxy cause, higher cardiorespiratory fitness in adult life, afford neuroprotective effects, and, hence, are associated with higher cognitive ability in adulthood, which is an alternative hypothesis driving the cognitive ability-PA associations (Belsky et al., 2015). However, this study also tested if the higher adulthood PA and cardiorespiratory fitness were predicted by childhood cognitive ability, a hypothesis named as "neuroselection" to reflect the nonrandom patterning of fitness across the cognitive ability distribution" (Belsky et al., 2015). The findings favored the neuroselection hypothesis and showed that higher general intelligence averaged across ages 7, 9, 11, and 13 years predicted a decreased likelihood of being a sedentary adult, and in the non-sedentary group higher general intelligence in childhood predicted higher levels of leisure-time PA (Belsky et al., 2015).

In all of these studies PA has, however, been self-reported. Self-reports of PA are vulnerable to response bias and over- or underestimation of true PA (Prince et al., 2008). Objective measures of PA offer more precise estimates of energy expenditure than do self-reports, are also able to capture all levels of PA which are not captured when using self-report measurements (Prince et al., 2008), and are accurate in assessing ST. Using self-reported PA may also partially explain, why in the study of Belsky et al. (2015) adulthood PA accounted for less than one fifth of the variation between childhood general intelligence and adulthood cardiorespiratory fitness. Hence, we carried out a study investigating if early childhood general intelligence, comprising general reasoning and verbal and visuo-motor abilities, was associated with PA and ST in young adulthood as self-reported and measured with omnidirectional accelerometers across an average of nine monitoring days.

Methods

Participants

Participants of the present study come from the Arvo Ylppö Longitudinal Study (AYLS) (Heinonen et al., 2008; Wolke, Sohne, Riegel, Ohrt, & Osterlund, 1998). They were recruited from a total of 15,311 deliveries in the seven maternity hospitals in Southern Finland in the county of Uusimaa between March 15, 1985 and March 14, 1986. The sample comprised 2,193 infants (1,193 boys). Of them 1,535 (867 boys) were admitted to the neonatal wards of the obstetric units, or transferred to the Neonatal Intensive Care Unit (NICU) of the Children's Hospital within ten days of birth. They ranged from severely ill preterm infants to infants requiring only brief inpatient observation. A large proportion of the hospitalized infants suffered from problems of a transient nature - hence, majority of the admitted infants had no diagnosed illness and were on the ward for observation or because of common problems of neonatal adaptation (Heinonen et al., 2008). An additional 658 (326 boys) infants not admitted to neonatal wards were prospectively recruited from births after every second hospitalized infant in the three largest maternity hospitals of the study area during the same period. Details of the study cohort are presented elsewhere (Heinonen et al., 2008; Riegel, Ohrt, Wolke, & Österlund, 1995; Wolke et al., 1998).

Figure 1 presents a flow chart of study participants and attrition. Of the 2,193 neonates of the original cohort, 1,737 (79.2%) participated in a follow-up visit at an average

age of 56 months (SD=0.7, Range=54.7-62.7). Of them, 1,583 (858 boys) underwent cognitive testing providing reliable test results at least in one of these tests.

In 2009 – 2012 we invited the still traceable 1,913 participants of the original cohort for a clinical and psychological follow-up (for 107 personal identification number was not available, for 173 participants of the original cohort addresses were not traceable, they were living abroad or would have needed accommodation for an overnight stay). Of the traceable, 1,136 participated (59.4%; 51.8% of the original cohort) in either of the two separate follow-up visits (clinical biomedical, psychological) at a mean age of 25.4 years (Range = 24.1 – 27.1) including objectively-measured and self-reported PA in 676 participants (59.5% of those who participated in the 25-year follow-up). We excluded those (n=74) who did not provide at least 4 days of valid objectively-measured PA data including at least 1 weekend day (Trost, McIver, & Pate, 2005) with at least 600 minutes of daily data (Matthews, Hagstromer, Pober, & Bowles, 2012) starting from 9 a.m. An additional six participants with congenital malformations or chromosomal abnormalities were excluded. Of the remaining 596 participants with valid PA data in young adulthood, data on cognitive abilities at 56 months of age were available for 500 (244 men) and they formed the analytic sample of the study.

Those in the analytic sample (n=500) and those who were invited but did not participate or were excluded from the analysis (n= 1,413) did not differ in gestational length, weight, height and body mass index (BMI) at the age of 56 months (all p-values>0.05); the analytic sample included more participants who were not hospitalized after birth (38.4 vs. 28.9%, p <0.001), women (51.2% vs. 43.7%, p <0.01), weighed more at birth (mean difference [MD] in standard deviation [SD] units of birth weight by gestational age and sex =0.20, p<0.01), had more frequently parent(s) with upper tertiary education (32.0% vs 24.1%, p<0.001), and scored higher on general reasoning (MD=4.56, p<0.001), verbal competence (MD=2.50, p<0.01), language comprehension (MD=2.73, p<0.01) and visuo-motor integration (MD=4.63, p<0.001) at the age of 56 months.

The childhood study protocol was approved by the ethics committees of the Helsinki City Maternity Hospital, the Helsinki University Central Hospital, and the Jorvi Hospital and in adulthood by the Coordinating Ethics Committee of the Helsinki and Uusimaa Hospital District. An informed consent was obtained from parents (childhood) and participants (adulthood).

Measures

Cognitive Ability at 56 months

The test battery included four tests. General reasoning was measured using the Columbia Mental Maturity Scale (Burgemeister, Blum, & Lorge, 1954) which is a non-verbal cognitive ability test for 3-10-year children consisting of 100 cards displaying a set of 3 to 5 drawings from which the child has to select the one that is different from or unrelated to the others. Verbal competence (expressive vocabulary) was measured by a Finnish translation of the verbal competence test devised by Kiese and Kozielski for 3-5-year-old children (Kieze & Kozielski, 1979). It is composed of 82 picture-naming tasks and is similar to the Peabody picture vocabulary test (Dunn & Markwardt, 1970) that is frequently used to assess verbal intelligence. Language comprehension was assessed with the Logopädisher Sprachverständnis Test devised by Wettstein (Wettstein, 1983), which consists of three parts (A-C). In this study we used the part A of this test for 4-8-year-old children, which includes a set of standard toys with which the child is asked to follow the actions verbally requested by the examiner (Gutbrod, Wolke, Soehne, Ohrt, & Riegel, 2000). Visuo-motor integration was measured using the Beery Scale for 3-15-year old children (Beery, 1982) . The child is asked to copy 12 geometrical figures that are presented in the order of increasing difficulty. All test scores were corrected for age at measurement.

Because the cognitive ability tests scores were correlated with each other (Pearson r's 0.20-0.47, all p-values<0.001), we computed principal components analysis which yielded one factor with an eigenvalue above one (eigenvalue 2.1) explaining 51.7% of the total variance. All the cognitive test scores loaded highly on this one factor (factor loadings for general reasoning=0.79, verbal competence=0.76, language comprehension=0.70, visuo-motor integration = 0.62). This general intelligence factor score (mean of 0 and SD of 1) was used as a primary predictor in our analyses.

Objectively-measured PA

PA was objectively monitored using omnidirectional accelerometer (Actiwatch AW7; Cambridge Neurotechnology Ltd, Cambridge, United Kingdom). The accelerometer was worn on the nondominant wrist. Activity counts were recorded using 1-minute epochs. A valid day consisted of a day with at least 600 minutes of data (Matthews et al., 2012) from 9 a.m. onwards. Days with night shift at work, sick leave or illness that may have an effect on physical activity were excluded. Of the measured 6090 days, 326 (5.4%) days were excluded. Participants having at least four valid monitoring days (Trost, McIver, & Pate, 2005), including at least one weekend day, were included into the analysis. In total, recordings for 74 individuals not meeting these criteria were excluded. PA was calculated over an average of 9.1 (SD=1.28; Range=4-10; Median=10.0) valid days.

We calculated the overall daily PA described as counts per minute (cpm) as an indicator of the total volume of PA (average intensity of PA). We divided total counts by monitoring time (min) per day and averaged over the measurement period for each participant.

Because we are not aware of a validation study for Actiwatch for the PA intensity cut-off points for adults, we used PA intensity cut-off points based on a calibration study for this wrist-worn Actiwatch in children as described (Ekblom, Nyberg, Bak, Ekelund, & Marcus, 2012). These cut-offs have, however, been used previously also in studies in adults (Kaseva et al., 2015). We used a cut-off of 320 cpm for ST representing 1.5 metabolic equivalents (MET) threshold, a cut-off of 321 – 1047 cpm for light PA representing <1.5 and > 3 METs, a cut-off of 1048 – 1623 cpm for moderate PA representing 3 – 5.9 METs, and a cut-off of ≥ 1624 cpm for vigorous PA representing ≥ 6 METs. We summed moderate and vigorous PA to present moderate-to-vigorous physical activity (MVPA) as recommended (Routen, Upton, Edwards, & Peters, 2012). We then calculated average time spent in ST, light PA and moderate to vigorous PA daily in minutes.

Self-reported PA

The questionnaire or parts of it have been extensively used in health-related population studies (Borodulin et al., 2016; Kajantie et al., 2010). The self-report comprised questions on physical demandingness of work, time spent walking, biking, or otherwise exercising daily in two-way commuting trip, how much an average one exercises and stresses oneself physically in leisure-time, and how much time one spends gardening, cleaning, doing household reparations, or similar activities in a day. The four-point response options are shown in Table 1.

Covariates and confounders

These, chosen on the basis of earlier literature, included sex (men/women), age (years) in adulthood, BMI (kg/m^2) calculated from weight and height measured in a clinic and transformed into BMI-for-age standard deviation (SD) scores using national growth references for girls and boys (for growth references Saari et al., 2011; Lawlor et al., 2006 for associations between cognitive ability and obesity), and mean of valid minutes of measurement period for PA. We further adjusted for self-reported alcohol consumption (g/week) (Corley et al., 2010), smoking status (yes, ex-smoker, no) (Batty & Deary, 2004), average daily intakes of energy (kcal/day), and fruit and vegetable consumption (g/day]) (Reinivuo, Hirvonen, Ovaskainen, Korhonen, & Valsta, 2010 for calculating dietary intake; Chandola et al., 2006 for associations between cognitive ability and dietary intake). Adjustments were also made for childhood socioeconomic status (Batty & Deary, 2004) using mother-reported parental education (highest of either parent) at 56 months as a proxy, own education in adulthood (Batty et al., 2007; Chandola et al., 2006; Gale et al., 2009) as self-reported (primary/lower secondary or less, upper secondary, lower tertiary, upper tertiary; we assigned participants studying for lower tertiary, n=90, and upper tertiary, n=145, education into their respective categories), and birth weight (Batty & Deary, 2004) standardized for gestational age and sex derived from hospital birth records. All categorical variables were dummy coded.

Statistical Analysis

We examined the associations between childhood general intelligence factor score and objectively-measured overall daily PA, ST, time spent in light PA and in MVPA by using generalized linear models (GLM) specifying a normal reference distribution. To improve linear model fitting MVPA was cube root transformed for these analyses (raw values are given in tables to facilitate interpretation). To examine if the childhood general intelligence factor score was associated with self-reported PA we used GLM specifying ordinal logistic reference distribution.

We report the associations first as adjusted for sex, age in adulthood, BMI-for-age SD score at 56 months and mean of valid minutes of measurement period for PA (model 1). We then made adjustments for model 1 covariates/confounders plus lifestyle in adulthood (model 2); model 1 covariates/confounders plus parental education at 56 months (model 3); model 1 covariates/confounders plus own attained education at 25 years (model 4); and model 1 covariates/confounders plus birth weight standardized by gestational age and sex (model 5).

We also tested whether the associations were non-linear by including a cognitive ability -product term in the regression equation following a linear term main effect and model 1 covariates/confounders.

Results

Table 1 shows characteristics of the sample. Objectively-measured PA variables were highly correlated with each other (Pearson r's │ -0.86 - 0.85 │; all p-values<0.001). Of the self-reported PA variables only physical strenuousness of work was correlated with longer time spent in leisure-time non-conditioning PA (Spearman rho 0.12, p=0.01; p-values for other correlations>0.05).

Table 2 shows that objectively-measured and self-reported PA were associated, such that higher physical demandingness of the work and longer time spent in non-conditioning leisure-time PA were associated with higher objectively-measured overall daily PA, less ST, and longer time spent in light PA and MVPA. Also, higher leisure-time conditioning PA was associated with higher objectively-measured overall daily PA and longer time spent in MVPA.

Higher parental education in childhood was correlated with higher adulthood education (Spearman rho 0.41, $p<0.001$), and higher childhood and adulthood education were associated with lower objectively-measured overall daily PA (-14.2 and -17.3 and CPM/day per one level increase in childhood and adulthood education, respectively, $p<0.001$), higher ST (17.8 and 27.0 minutes/day per each one level increase in childhood and adulthood education, $p<0.001$), and shorter time spent in light PA (-16.1 and -22.4 minutes/day per each one level increase in childhood and adulthood education, $p<0.001$).

Associations between childhood cognitive ability and objectively-measured PA

Table 3 shows that after adjusting for sex, age, BMI-for-age SD score at 56 months and mean of valid minutes of measurement period for PA (model 1), per each one SD increase in the childhood general intelligence factor score, overall daily PA decreased by -8.99 CPM/day, ST increased by 14.93 minutes/day, and time spent in light PA decreased by -14.39 minutes/day. The association with overall daily PA did not survive any further covariate adjustments, and the association with ST and light PA did not survive adjustment for childhood parental or own education (Table 3).

Tests of non-linear associations between the childhood general intelligence factor score and objectively-measured PA were not significant ($p>0.051$) (Table 3).

Supplementary table 1 shows associations between different domains of childhood cognitive ability and objectively-measured PA.

Associations between childhood cognitive ability and self-reported PA

Table 4 shows that after model 1 adjustments, per each one SD unit increase in the general intelligence factor score, the odds per each level increase in physical demandingness of the work decreased by 38%, and the odds per each level increase in time spent in non-conditioning leisure-time PA decreased by 31%. These associations survived covariate adjustments, except the association with occupational PA was rendered non-significant when adjusted for own education (Table 4). There were no significant associations between childhood general intelligence factor score and adulthood commuting PA and leisure-time conditioning PA (Table 4).

Additional analyses

Because of the pattern of our findings, pointing to lower adulthood PA in those with a higher childhood general intelligence factor score, we additionally tested if the associations between childhood general intelligence factor score and overall daily PA would differ between participants reporting different levels of occupational, commuting, and leisure-time conditioning and non-conditioning PA. Because participants were unevenly distributed in the categories of these variables resulting in small cell sizes (Table 1), we dichotomized the self-report variables, except time spent in leisure-time conditioning PA had three categories.

Table 5 shows that per each one SD increase in the childhood general intelligence factor score, overall daily PA decreased by -12.31 CPM/day among those who reported less than 30 minutes of daily commuting PA. There were no other significant associations between childhood general intelligence factor score and overall daily PA in the categories of occupational and leisure-time conditioning and non-conditioning PA (p-values>0.07) (Table 5).

We also tested if the participant’s own young adulthood education mediated the associations between childhood general intelligence factor score and objectively-measured PA, because when we adjusted for own education all the significant associations were rendered non-significant (Table 3, Supplementary table 1). Mediation was tested using the bootstrapping method with 5000 bootstrapping re-samples with bias-corrected confidence intervals. Supplementary figure 1 shows that the associations between higher childhood general intelligence and lower daily PA (Panel A), higher ST (Panel B) and lower light PA (Panel C) were mediated, at least partially, by own education. Together the childhood general intelligence factor score and own young adulthood education accounted for 5-9% of the variance in objectively-measured PA. Supplementary figure 2 shows that adulthood education also, at least partially, mediated the associations of higher childhood general intelligence with reported lower physical demandingness of work (Panel A) and shorter time spent in non-conditioning leisure-time PA (Panel B).

Discussion

To our knowledge, this is the first study to examine associations between childhood cognitive ability and objectively-measured PA and ST in young adulthood. Our findings are in contrast to what we expected based on the cognitive epidemiology framework (Deary & Batty, 2007) and previous studies, that have shown that higher childhood general intelligence/mental ability is associated with more intense and frequent self-reported PA (Batty et al., 2007; Belsky et al., 2015; Kanazawa, 2013), and with less ST in adulthood (Belsky et al., 2015). In our sample of young adults with high variability in PA, per each one SD increase in the childhood general intelligence factor score, objectively-measured overall daily PA decreased by -8.99 CPM/day, ST increased by 14.93 minutes/day and time spent in light PA decreased by -14.39 minutes/day.

These associations were significant when we made adjustments for sex, age at testing in adulthood, childhood BMI and the mean of valid minutes of the measurement period for PA. While some of these associations remained significant when we made further adjustments for lifestyle factors, including smoking, alcohol consumption and intake of fruits/vegetables, and parental education in childhood, all the associations between general intelligence and objectively-measured PA were rendered non-significant when we made adjustment for own achieved/to be achieved education in adulthood. Mediation analyses revealed that higher adulthood achieved/to be achieved education at least partially mediated the associations between childhood general intelligence and objectively-measured PA with childhood intelligence and adulthood education accounting together for 5-9% of the total variance in adulthood objectively-measured PA. This may suggest that lower overall daily PA, higher ST and shorter time spent in light PA reflect lower strenuousness of any daily activity reflected by higher education or studying for the target education, and consequently lower physical demandingness of the work.

The associations with self-reported PA paralleled the objectively-measured PA – a finding which is not surprising given that in our study objectively-measured and self-reported PA were associated. These findings showed that per each one SD increase in childhood general intelligence, the odds per each level increase in self-reported physical demandingness of the work and in self-reported time spent in non-conditioning leisure-time PA decreased by 38% and 31%, respectively. Adulthood education also, at least partially, mediated these associations. Yet, we did not find evidence that higher childhood general intelligence was associated with self-reported commuting or leisure-time conditioning PA. These findings emphasize the need to study composition of PA, not only the overall level of daily PA, in future epidemiologic studies.

The age-stage of our sample may give insight into our findings. Transition from late adolescence into early adulthood is a period when PA tends to decline (Gordon-Larsen, Nelson, & Popkin, 2004; Kwan, Cairney, Faulkner, & Pullenayegum, 2012), especially among men entering to college/university (Gordon-Larsen et al., 2004; Kwan et al., 2012). In our study sample 47% were still studying. Also, important events in the transition to adulthood, such as getting married and having children, may change PA practices especially among young women (Engberg et al., 2012). Even though, PA showed high variability in this sample, we are not able to say if childhood general intelligence will predict a more sedentary lifestyle later in adulthood in our sample, though ST tends to increase, rather than decrease, with age (Hallal et al., 2012). Yet, despite these mean level changes in adulthood, PA during adulthood has been shown to be at least moderately stable (Pinto Pereira, Li, & Power, 2015).

Assuming that PA patterns persist across time, our findings may carry an important health message: increasing awareness of the benefits of PA-related health promotion should be targeted to young adults whose daily activities comprise more sitting and hence ST.

Strengths of our study include a relatively long follow-up, and measurement of cognitive abilities using validated neuropsychological tests, measurement of both objective PA across an average of 9 days resulting in 5764 monitoring days in the entire sample, and self-reported PA. Limitations exist as well. We were not able to divide objectively measured PA and ST into working/studying and leisure-time hours. In future, it would be important to focus separately on objectively-measured PA and ST in working/studying hours and in leisure-time hours. Further, in the current study, cognitive abilities were assessed at only one point in childhood and PA at only one point in adulthood. Repeated assessment from childhood to adulthood would have enabled us to test associations between change scores across time, and also address if childhood PA offered neuroprotective effects (cf. Belsky et al., 2015). Finally, in longitudinal studies, loss to follow-up is inevitable and may cause a potential selection bias. Participants in the current study had better-educated parents, higher cognitive ability in childhood, were more often women, more often non-hospitalized controls and weighed more at birth. Hence, our findings may not generalize to populations that vary in these characteristics from our sample.

Our findings suggest that higher childhood general intelligence is associated with lower objectively-measured overall daily PA, higher ST, and shorter time spent in light PA. These findings were paralleled by findings with self-reported PA. Whether these findings persist to ages beyond young adulthood is a subject of future follow-up studies. At present the associations may reflect behaviors that are related to engagement in studying and to transitioning into adulthood, even though the sample varied in both objectively-measured and self-reported PA, rather than intelligence-related adherence to a physically active lifestyle.

References

Batty, G. D., & Deary, I. J. (2004). Early life intelligence and adult health. *BMJ (Clinical Research Ed.), 329*(7466), 585-586. doi:10.1136/bmj.329.7466.585

Batty, G. D., Deary, I. J., & Macintyre, S. (2006). Childhood IQ and life course socioeconomic position in relation to alcohol induced hangovers in adulthood: The aberdeen children of the 1950s study. *Journal of Epidemiology and Community Health, 60*(10), 872-874.

Batty, G. D., Deary, I. J., & Macintyre, S. (2007). Childhood IQ in relation to risk factors for premature mortality in middle-aged persons: The aberdeen children of the 1950s study. *Journal of Epidemiology and Community Health, 61*(3), 241-247. doi:10.1136/jech.2006.048215

Batty, G. D., Deary, I. J., Schoon, I., Emslie, C., Hunt, K., & Gale, C. R. (2008). Childhood mental ability and adult alcohol intake and alcohol problems: The 1970 british cohort study. *American Journal of Public Health, 98*(12), 2237-2243. doi:10.2105/AJPH.2007.109488; 10.2105/AJPH.2007.109488

Batty, G. D., Deary, I. J., Schoon, I., & Gale, C. R. (2007). Childhood mental ability in relation to food intake and physical activity in adulthood: The 1970 british cohort study. *Pediatrics, 119*(1), e38-45. doi:10.1542/peds.2006-1831

Beery, K. (1982). *Revised administration, scoring, and teaching manual for the developmental test of visual-motor integration*. Cleveland-Toronto: Modern Curriculum Press.

Belsky, D. W., Caspi, A., Goldman-Mellor, S., Meier, M. H., Ramrakha, S., Poulton, R., & Moffitt, T. E. (2013). Is obesity associated with a decline in intelligence quotient during the first half of the life course? *American Journal of Epidemiology*, *178*(9), 1461-1468. doi:10.1093/aje/kwt135 [doi]

Belsky, D. W., Caspi, A., Israel, S., Blumenthal, J. A., Poulton, R., & Moffitt, T. E. (2015). Cardiorespiratory fitness and cognitive function in midlife: Neuroprotection or neuroselection? *Annals of Neurology, 77*(4), 607-617. doi:10.1002/ana.24356 [doi]

Borodulin, K., Harald, K., Jousilahti, P., Laatikainen, T., Mannisto, S., & Vartiainen, E. (2016). Time trends in physical activity from 1982 to 2012 in finland. *Scandinavian Journal of Medicine & Science in Sports, 26*(1), 93-100. doi:10.1111/sms.12401 [doi]

Burgemeister, B. B., Blum, L. H., & Lorge, I. (1954). *The columbia mental maturiturity scale (manual)*. New YOrk: NY: Yonkers-on-Hudson.

Chandola, T., Deary, I. J., Blane, D., & Batty, G. D. (2006). Childhood IQ in relation to obesity and weight gain in adult life: The national child development (1958) study. *International Journal of Obesity (2005), 30*(9), 1422-1432. doi:10.1038/sj.ijo.0803279

Corley, J., Gow, A. J., Starr, J. M., & Deary, I. J. (2010). Is body mass index in old age related to cognitive abilities? the lothian birth cohort 1936 study. *Psychology and Aging, 25*(4), 867-875. doi:10.1037/a0020301; 10.1037/a0020301

Daly, M., & Egan, M. (2016). Childhood cognitive ability and smoking initiation, relapse, and cessation throughout adulthood: Evidence from two british cohort studies. *Addiction (Abingdon, England),* doi:10.1111/add.13554 [doi]

Deary, I. J., & Batty, G. D. (2007). Cognitive epidemiology. *Journal of Epidemiology and Community Health, 61*(5), 378-384. doi:10.1136/jech.2005.039206

Dunn, L., & Markwardt, F. (1970). *Peabody individual achievement test* . Circle Pines, MN: American Guidance Service.

Ekblom, O., Nyberg, G., Bak, E. E., Ekelund, U., & Marcus, C. (2012). Validity and comparability of a wrist-worn accelerometer in children. *Journal of Physical Activity & Health, 9*(3), 389-393.

Engberg, E., Alen, M., Kukkonen-Harjula, K., Peltonen, J. E., Tikkanen, H. O., & Pekkarinen, H. (2012). Life events and change in leisure time physical activity: A systematic review. *Sports Medicine (Auckland, N.Z.), 42*(5), 433-447. doi:10.2165/11597610-000000000-00000 [doi]

Gale, C. R., Batty, G. D., Cooper, C., & Deary, I. J. (2009). Psychomotor coordination and intelligence in childhood and health in adulthood--testing the system integrity hypothesis. *Psychosomatic Medicine, 71*(6), 675-681. doi.org/10.1097/PSY.0b013e3181a63b2e

Gordon-Larsen, P., Nelson, M. C., & Popkin, B. M. (2004). Longitudinal physical activity and sedentary behavior trends: Adolescence to adulthood. *American Journal of Preventive Medicine, 27*(4), 277-283. DOI:10.1016/j.amepre.2004.07.006

Gutbrod, T., Wolke, D., Soehne, B., Ohrt, B., & Riegel, K. (2000). Effects of gestation and birth weight on the growth and development of very low birthweight small for gestational age infants: A matched group comparison. *Archives of Disease in Childhood.Fetal and Neonatal Edition, 82*(3), F208-14.

Hallal, P. C., Andersen, L. B., Bull, F. C., Guthold, R., Haskell, W., Ekelund, U., & Lancet Physical Activity Series Working Group. (2012). Global physical activity levels: Surveillance progress, pitfalls, and prospects. *Lancet (London, England), 380*(9838), 247-257. doi:10.1016/S0140-6736(12)60646-1 [doi]

Hart, C. L., Taylor, M. D., Smith, G. D., Whalley, L. J., Starr, J. M., Hole, D. J., . . . Deary, I. J. (2004). Childhood IQ and cardiovascular disease in adulthood: Prospective observational study linking the scottish mental survey 1932 and the midspan studies. *Social Science & Medicine (1982), 59*(10), 2131-2138. doi:10.1016/j.socscimed.2004.03.016

Heinonen, K., Raikkonen, K., Pesonen, A. K., Kajantie, E., Andersson, S., Eriksson, J. G., . . . Lano, A. (2008). Prenatal and postnatal growth and cognitive abilities at 56 months of age: A longitudinal study of infants born at term. *Pediatrics, 121*(5), e1325-33. http://dx.doi.org/10.1542/

peds.2007-1172 Kajantie, E., Strang-Karlsson, S., Hovi, P., Raikkonen, K., Pesonen, A. K., Heinonen, K., . . . Andersson, S. (2010). Adults born at very low birth weight exercise less than their peers born at term. *The Journal of Pediatrics, 157*(4), 610-6, 616.e1. doi:10.1016/j.jpeds.2010.04.002 [doi]

Kanazawa, S. (2013). Childhood intelligence and adult obesity. *Obesity (Silver Spring, Md.), 21*(3), 434-440. doi.org/10.1002/oby.20018

Kaseva, N., Martikainen, S., Tammelin, T., Hovi, P., Jarvenpaa, A. L., Andersson, S., . . . Kajantie, E. (2015). Objectively measured physical activity in young adults born preterm at very low birth weight. *The Journal of Pediatrics, 166*(2), 474-476. doi:10.1016/j.jpeds.2014.10.018 [doi]

Kieze, C., & Kozielski, P. (1979). *Aktiver wortschatztest fur drei- bis sechsjährige kinder* (AWST 3–6. ed.). Weinheim, Germany: Beltz.

Kubicka, L., Matejcek, Z., Dytrych, Z., & Roth, Z. (2001). IQ and personality traits assessed in childhood as predictors of drinking and smoking behaviour in middle-aged adults: A 24-year follow-up study. *Addiction (Abingdon, England), 96*(11), 1615-1628. doi:10.1080/09652140120080741 [doi]

Kumpulainen, S. M., Heinonen, K., Salonen, M. K., Andersson, S., Wolke, D., Kajantie, E., . . . Raikkonen, K. (2016). Childhood cognitive ability and body composition in adulthood. *Nutrition & Diabetes, 6*(8), e223. doi:10.1038/nutd.2016.30 [doi]

Kwan, M. Y., Cairney, J., Faulkner, G. E., & Pullenayegum, E. E. (2012). Physical activity and other health-risk behaviors during the transition into early adulthood: A longitudinal cohort study. *American Journal of Preventive Medicine, 42*(1), 14-20. doi:http://dx.doi.org/10.1016/j.amepre.2011.08.026

Lawlor, D. A., Clark, H., Davey Smith, G., & Leon, D. A. (2006). Childhood intelligence, educational attainment and adult body mass index: Findings from a prospective cohort and within sibling-pairs analysis. *International Journal of Obesity (2005), 30*(12), 1758-1765. doi:10.1038/sj.ijo.0803330

Martin, L. T., Fitzmaurice, G. M., Kindlon, D. J., & Buka, S. L. (2004). Cognitive performance in childhood and early adult illness: A prospective cohort study. *Journal of Epidemiology and Community Health, 58*(8), 674-679. doi:10.1136/jech.2003.016444

Matthews, C. E., Hagstromer, M., Pober, D. M., & Bowles, H. R. (2012). Best practices for using physical activity monitors in population-based research. *Medicine and Science in Sports and Exercise, 44*(1 Suppl 1), S68-76. doi:10.1249/MSS.0b013e3182399e5b [doi]

Mortensen, L. H., Sorensen, T. I., & Gronbaek, M. (2005). Intelligence in relation to later beverage preference and alcohol intake. *Addiction (Abingdon, England), 100*(10), 1445-1452. http://dx.doi.org/10.1111/j.1360-0443.2005.01229.x

Pinto Pereira, S. M., Li, L., & Power, C. (2015). Early life factors and adult leisure time physical inactivity stability and change. *Medicine and Science in Sports and Exercise, 47*(9), 1841-1848. doi:10.1249/MSS.0000000000000610 [doi]

Prince, S. A., Adamo, K. B., Hamel, M. E., Hardt, J., Connor Gorber, S., & Tremblay, M. (2008). A comparison of direct versus self-report measures for assessing physical activity in adults: A systematic review. *The International Journal of Behavioral Nutrition and Physical Activity, 5*, 56-5868-5-56. doi:10.1186/1479-5868-5-56 [doi]

Reinivuo, H., Hirvonen, T., Ovaskainen, M. L., Korhonen, T., & Valsta, L. M. (2010). Dietary survey methodology of FINDIET 2007 with a risk assessment perspective. *Public Health Nutrition, 13*(6A), 915-919. doi:10.1017/S1368980010001096 [doi]

Rhodes, R. E., Mark, R. S., & Temmel, C. P. (2012). Adult sedentary behavior: A systematic review. *American Journal of Preventive Medicine, 42*(3), e3-28. doi:10.1016/j.amepre.2011.10.020 [doi]

Riegel, K., Ohrt, B., Wolke, D., & Österlund, K. (1995). *Die entwicklung gefährdet geborener kinder bis zum funften lebensjahr*. Ferdinand Enke Verlag Stuttgart.

Routen, A. C., Upton, D., Edwards, M. G., & Peters, D. M. (2012). Intra- and inter-instrument reliability of the actiwatch 4 accelerometer in a mechanical laboratory setting. *Journal of Human Kinetics, 31*, 17-24. doi:10.2478/v10078-012-0002-z [doi]

Saari, A., Sankilampi, U., Hannila, M. L., Kiviniemi, V., Kesseli, K., & Dunkel, L. (2011). New finnish growth references for children and adolescents aged 0 to 20 years: Length/height-for-age, weight-for-length/height, and body mass index-for-age. *Annals of Medicine, 43*(3), 235-248. doi:10.3109/07853890.2010.515603 [doi]

Taylor, M. D., Hart, C. L., Davey Smith, G., Starr, J. M., Hole, D. J., Whalley, L. J., . . . Deary, I. J. (2003). Childhood mental ability and smoking cessation in adulthood: Prospective observational study linking the scottish mental survey 1932 and the midspan studies. *Journal of Epidemiology and Community Health, 57*(6), 464-465.

Thorp, A. A., Owen, N., Neuhaus, M., & Dunstan, D. W. (2011). Sedentary behaviors and subsequent health outcomes in adults: A systematic review of longitudinal studies, 1996–2011. *American Journal of Preventive Medicine, 41*(2), 207-215. doi:http://dx.doi.org/10.1016/j.amepre.2011.05.004

Trost, S. G., McIver, K. L., & Pate, R. R. (2005). Conducting accelerometer-based activity assessments in field-based research. *Medicine and Science in Sports and Exercise, 37*(11 Suppl), S531-43. doi:00005768-200511001-00006 [pii]

Wennber, P., Andersson, T., & Bohman, M. (2002). Psychosocial characteristics at age 10; differentiating between adult alcohol use pathways: A prospective longitudinal study. *Addictive Behaviors, 27*(1), 115-130.

Wettstein, P. (1983). *LSVT: Logopädischer sprachverständnis-test*. Zurich,Switzerland: Heilpädagogisches Seminar;.

WHO. (2009). *Global health risks: Mortality and burden of disease attributable to selected major risks.* (). Geneva: World Health Organization.

Wolke, D., Sohne, B., Riegel, K., Ohrt, B., & Osterlund, K. (1998). An epidemiologic longitudinal study of sleeping problems and feeding experience of preterm and term children in southern finland: Comparison with a southern german population sample. *The Journal of Pediatrics, 133*(2), 224-231. http://dx.doi.org/10.1016/S0022-3476(98)70224-0

Figure legends

Figure 1. Flow chart of the Arvo Ylppö Longitudinal Study participants and attrition.

Supplementary figure 1. Mediation analyses showing that childhood general intelligence act via adulthood education to impact on objectively-measured overall daily physical activity (PA) (Panel A), sedentary time (ST) (Panel B) and time spent in light PA (Panel C). The numbers represent unstandardized regression coefficients (B), 95% Confidence Intervals (CI), and p-values. The values are adjusted for sex, age, body-mass-index-for-age standard deviation score at 56 months and mean of valid minutes of measurement period for PA.

Supplementary figure 2. Mediation analyses showing that childhood general intelligence act via adulthood education to impact on self-reported occupational physical activity (PA) (with higher values reflecting higher physical demandingness of work) (Panel A) and time spent in non-conditioning leisure-time PA (with higher values reflecting longer time spent in non-conditioning leisure-time PA) (Panel B). The numbers represent unstandardized regression coefficients (B), 95% Confidence Intervals (CI), and p-values. The values are adjusted for sex, age, body-mass-index-for-age standard deviation score at 56 months and mean of valid minutes of measurement period for PA.

Table 1. Characteristics of the sample

	Mean (SD) /n (%)
At Birth	
Sex (boys)	244 (48.8%)
Gestation length (weeks)	38.8 (2.8)
Birth weight (grams)*	3358.0 (768.6)
Birth weight (standard deviation units by gestational age and sex)	-0.1 (1.3)
At 56-month follow-up	
Age (months)	56.5 (0.4)
Weight (kg)*	18.2 (2.6)
Height (cm)*	108.2 (4.5)
Body mass index (kg/m^2)*	15.5 (1.5)
Highest education of either parent	
Basic/primary or less	46 (9.2%)
Upper secondary	104 (20.8%)
Lower tertiary	190 (38.0%)
Upper tertiary	160 (32.0%)
Cognitive ability (mean=100, standard deviation=15)*	
General reasoning	100.4 (16.3)
Visuo-motor integration	101.0 (14.6)
Verbal competence	100.6 (14.5)
Language comprehension	101.2 (14.0)
At 25-year follow-up	
Age (years)	25.3 (0.6)
Weight (kg)*	72.3 (15.1)
Height (cm)*	173.0 (9.2)
Body mass index (kg/m^2)*	24.0 (4.2)
Level of education*	
Basic/lower secondary or less	19 (3.9%)
Upper secondary	154 (31.4%)
Lower tertiary or studying for it	151 (30.8%)
Upper tertiary or studying for it	167 (34.0%)
Alcohol consumption (g/week)*	67.7 (85.60)
Smoking status*	
No	116 (23.5%)
Ex-smoker	203 (41.2%)
Yes	174 (35.3%)
Fruit and vegetable intake, g/d*	451.2 (285.2)
Energy intake, kcal/d*	2201.8 (790.1)
Objectively-measured physical activity	
Overall daily physical activity (cpm/day)	286.8 (85.3)
Time spent in moderate-to-vigorous physical activity (min/day)	31.2 (24.6)
Time spent in light physical activity (min/day)	254.4 (82.4)
Time spent in sedentary time (min/ day)	582.9 (98.8)
Valid minutes of measurement period (min/day)	868.6 (55.1)
Self-reported physical activity*	

Occupational physical activity	
Mostly sitting	247 (55.0%)
Quite a lot of walking, no lifting	81 (18.0%)
Lot of walking and lifting	95 (21.2%)
Physically very demanding work	26 (5.8%)
Commuting physical activity; minutes spent walking, biking, or otherwise exercising daily	
<15 min	191 (42.5%)
15 min to <30 min	138 (30.7)
30 min to <60 min	98 (21.8%)
60 min or more	22 (4.9%)
Leisure-time conditioning physical activity: average exercise and physical stress in leisure time	
I read, watch TV and do tasks that do not demand much movement and do not cause physical strain	114 (24.2%)
I walk, cycle, or perform other exercise not causing substantial perspiration at least 4 hours/week	131 (27.8%)
I exercise to maintain my physical condition for at least 3 hours/week	189 (40.0%)
I regularly train for competitive sports for several times a week	38 (8.1%)
Duration of leisure-time non-conditioning physical activity	
<30min	272 (57.1%)
30 min to <60min	134 (28.2%)
60 min or more	70 (14.7%)

Note.* Data on birth weight was missing in 1 participants, on weight, height and body mass index at 56 months of age in 5 to 11 participants, on cognitive abilities at 56 months of age in 9 to 32 participants, on weight, height and body mass index at 25 years of age in 1 participants, on level of education in 9 participants, on alcohol consumption, smoking status, fruit and vegetable intake and energy intake in 7 to 32 participants and on self-reported physical activity in 24 to 51 participants.

Table 2. Associations between self-reported and objectively-measured physical activity at 25 years of age

Self-reported physical activity	**Objectively-measured physical activity**											
	Overall daily physical activity (cpm/day)			**Sedentary time (min/day)**			**Light physical activity (min/day)**			**Moderate-to-vigorous physical activity (min/day)**		
	Mean difference	95% CI	P	Mean difference	95% CI	P	Mean difference	95% CI	P	Mean difference	95% CI	P
Occupational physical activity												
Mostly sitting	Reference			Reference			Reference			Reference		
Quite a lot of walking, no lifting	18.36	(-2.12, 38.83)	0.079	-33.45	(-56.85, -10.04)	**0.005**	30.51	(10.08, 50.93)	**0.003**	-0.36	(-5.42, 4.70)	0.600
Lot of walking and lifting	56.74	(35.37, 78.11)	**0.000**	-79.76	(-104.29, -55.24)	**0.000**	71.17	(51.12, 91.23)	**0.000**	8.61	(1.72, 15.50)	0.091
Physically very demanding work	66.23	(32.77, 99.69)	**0.000**	-70.87	(-107.81, -33.92)	**0.000**	73.56	(43.35, 103.78)	**0.000**	16.01	(2.12, 29.90)	**0.005**
Linear trend	*25.3*	*(17.24, 33.50)*	***0.000***	*-32.96*	*(-42.29, -23.62)*	***0.000***	*30.84*	*(23.30, 38.38)*	***0.000***	*4.53*	*(1.70, 7.36)*	***0.006***
Commuting physical activity; minutes spent walking, biking, or otherwise exercising daily												
<15 min	Reference			Reference			Reference			Reference		
15 min to <30 min	-1.08	(-19.88, 17.72)	0.910	1.26	(-19.42, 21.93)	0.905	1.66	(-15.63, 18.94)	0.851	-1.98	(-7.60, 3.65)	0.878
30 min to <60 min	-3.33	(-23.79, 17.12)	0.749	2.80	(-22.29, 27.88)	0.827	8.84	(-11.77, 29.45)	0.401	-3.97	(-9.59, 1.66)	0.445
60 min or more	24.09	(-10.44, 58.62)	0.172	-45.17	(-85.38, -4.95)	0.028	33.75	(-4.20, 71.69)	0.081	0.43	(-8.95, 9.80)	0.381
Linear trend	*1.99*	*(-6.61, 10.59)*	*0.650*	*-4.77*	*(-15.11, 5.57)*	*0.366*	*6.87*	*(-1.80, 15.54)*	*0.121*	*-1.19*	*(-3.62, 1.24)*	*0.872*
Leisure-time conditioning physical activity												
I read, watch TV and do tasks that do not demand much	Reference			Reference			Reference			Reference		

movement and do not cause physical strain												
I walk, cycle, or perform other exercise not causing substantial perspiration at least 4 hours/week	26.97	(5.87, 48.07)	**0.012**	-12.51	(-38.22, 13.19)	0.340	22.37	(0.76, 43.98)	0.043	8.26	(2.16, 14.35)	**0.003**
I exercise to maintain my physical condition for at least 3 hours/week	19.38	(1.26, 37.50)	**0.036**	6.87	(-15.14, 28.87)	0.541	9.88	(-8.99, 28.75)	0.305	8.17	(3.15, 13.20)	**0.000**
I regularly train for competitive sports for several times a week	52.21	(13.94, 90.48)	**0.008**	-9.39	(-43.47, 24.70)	0.589	6.42	(-23.87, 36.71)	0.678	21.79	(10.78, 32.81)	**0.000**
Linear trend	*11.54*	*(2.90, 20.18)*	***0.009***	*1.99*	*(-7.24, 11.21)*	*0.673*	*1.83*	*(-6.18, 9.83)*	*0.655*	*5.15*	*(2.70, 7.61)*	***0.000***
Duration of leisure-time non-conditioning physical activity												
<30min	Reference			Reference			Reference			Reference		
30 min to<60min	15.78	(-1.56, 33.12)	0.074	-21.60	(-42.42, -0.79)	**0.042**	22.61	(5.55, 39.67)	**0.009**	1.00	(-3.83, 5.83)	0.594
60 min or more	46.11	(23.75, 68.47)	**0.000**	-53.90	(-79.20, -28.59)	**0.000**	50.22	(29.07, 71.37)	**0.000**	8.35	(1.58, 15.11)	**0.004**
Linear trend	*21.44*	*(11.07, 31.81)*	***0.000***	*-25.76*	*(-37.57, -13.95)*	***0.000***	*24.56*	*(14.70, 34.41)*	***0.000***	*3.47*	*(0.37, 6.57)*	***0.011***

Note. P-values for moderate-to-vigorous physical activity are from a model where the variable was cube root transformed, raw values are presented to facilitate interpretation. CI confidence interval.

Table 3. Associations between childhood general intelligence factor score at the age of 56 months and objectively-measured physical activity at 25 years of age

General intelligence factor score, change per one standard deviation	**Overall daily physical activity**			**Sedentary time**			**Light physical activity**			**Moderate-to-vigorous physical activity**		
	CPM/ day	**95% CI**	**P**	**min/ day**	**95% CI**	**P**	**min/ day**	**95% CI**	**P**	**min/ day**	**95% CI**	**P**
Model 1	-8.99	(-17.51, -0.47)	**0.039**	14.93	(5.45, 24.40)	**0.002**	-14.39	(-22.49, -6.30)	**0.000**	-0.54	(-2.94, 1.87)	0.447
Model 2	-7.88	(-17.84, 2.08)	0.121	12.26	(1.01, 23.52)	**0.033**	-11.54	(-21.14, -1.93)	**0.019**	-0.72	(-3.44, 1.99)	0.368
Model 3	-3.86	(-13.28, 5.56)	0.422	8.65	(-1.78, 19.08)	0.104	-8.89	(-17.89, -0.12)	0.053	0.23	(-2.40, 2.87)	0.824
Model 4	4.52	(-13.75, 4.71)	0.337	7.76	(-2.49, 18.01)	0.138	-7.46	(-16.18, 1.27)	0.094	-0.30	(-0.12, 0.06)	0.354
Model 5	-8.25	(-16.77, 0.25)	0.057	14.05	(4.61, 23.49)	**0.004**	-13.61	(-21.70, -5.56)	**0.001**	-0.44	(-2.87, 1.99)	0.510
Non-linear	-4.39	(-10.40, 1.62)	0.152	3.25	(-3.59, 10.10)	0.352	-1.69	(-7.65, 4.27)	0.579	-1.56	(-3.152, 0.21)	0.051

Note. Model 1 refers to adjustment for sex, age in adulthood, body mass index-for-age SD score at 56 months and mean of valid minutes of measurement period for PA; Model 2 refers to model 1 covariates/confounders plus lifestyle (smoking, alcohol consumption and dietary intake) in adulthood; Model 3 refers to model 1 covariates/confounders plus parental education at 56 months; Model 4 refers to model 1 covariates/confounders plus own attained education in adulthood; Model 5 refers to model 1 covariates/confounders plus birth weight standardized by gestational age and sex; Non-linear refers to a model including cognitive ability squared term in a model that also includes cognitive ability linear term and model 1 covariates/confounders; Values are derived from generalized linear models with normal reference distribution; p-values for moderate-to-vigorous physical activity are from a model where the variable was cube root transformed, raw values are presented to facilitate interpretation. Abbreviations: CI=confidence interval; CPM=counts per minute.

Table 4. Associations between childhood cognitive abilities at the age of 56 months and self-reported occupational, commuting, and leisure-time conditioning and non-conditioning physical activity at 25 years of age

General intelligence factor score,	**Occupational physical activity**			**Commuting physical activity**			**Leisure-time conditioning physical activity**			**Leisure-time non-conditioning physical activity**		
change per one standard deviation	OR	95% CI	P	OR	95% CI	P	OR	95% CI	P	OR	95% CI	P
Model 1	0.62	(0.49, 0.78)	**0.000**	0.92	(0.73, 1.16)	0.475	1.12	(0.94, 1.33)	0.221	0.69	(0.55, 0.87)	**0.001**
Model 2	0.67	(0.52, 0.85)	**0.001**	0.90	(0.71, 1.15)	0.409	1.05	(0.88, 1.26)	0.592	0.66	(0.52, 0.83)	**0.000**
Model 3	0.76	(0.59, 0.96)	**0.022**	0.92	(0.73, 1.17)	0.497	1.08	(0.89, 1.32)	0.426	0.75	(0.58, 0.97)	**0.025**
Model 4	0.86	(0.68, 1.10)	0.231	0.86	(0.67, 1.10)	0.218	1.03	(0.85, 1.26)	0.759	0.76	(0.60, 0.96)	**0.020**
Model 5	0.62	(0.49, 0.78)	**0.000**	0.94	(0.75, 1.19)	0.605	1.11	(0.93, 1.33)	0.245	0.68	(0.54, 0.85)	**0.001**
Non-linear	1.02	(0.87, 1.20)	0.803	1.02	(0.86, 1.20)	0.854	0.93	(0.82, 1.04)	0.202	1.05	(0.89, 1.24)	0.553

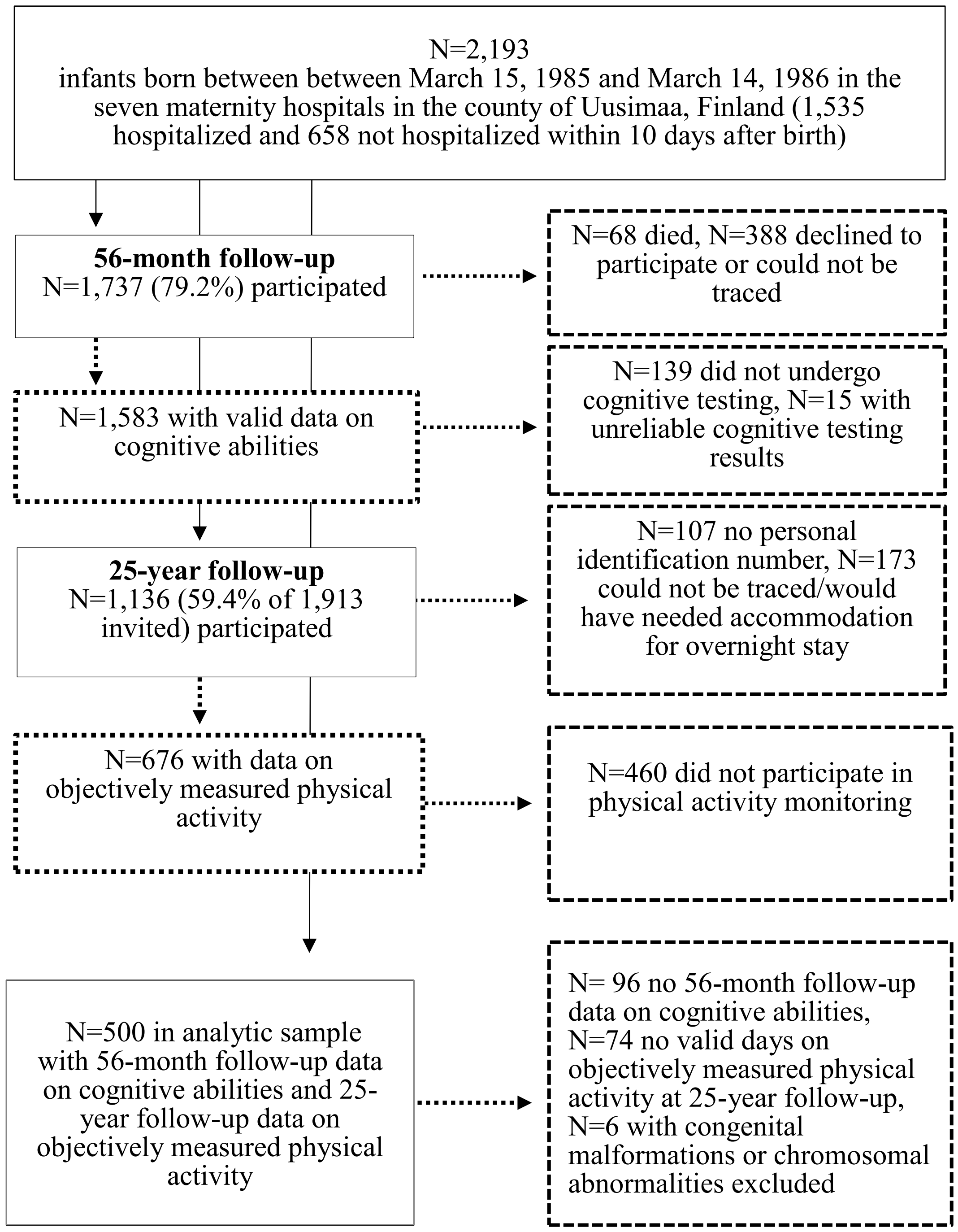
Note. Model 1 refers to adjustment for sex, age in adulthood, body mass index-for-age SD score at 56 months and mean of valid minutes of measurement period; Model 2 refers to model 1 covariates/confounders plus lifestyle (smoking, alcohol consumption and dietary intake) in adulthood; Model 3 refers to model 1 covariates/confounders plus parental education at 56 months; Model 4 refers to model 1 covariates/confounders plus own attained education in adulthood; Model 5 refers to model 1 covariates/confounders plus birth weight standardized by gestational age and sex; Non-linear refers to a model including cognitive ability squared term in a model that also includes cognitive ability linear term and model 1 covariates/confounders; Values are derived from generalized linear models with ordinal logistic reference distribution. Abbreviations: CI=confidence interval; OR=odds ratio per one level change in outcome.

Table 5. Associations between general intelligence factor score at the age of 56 months and objectively-measured physical activity at 25 years of age in different categories of occupational, commuting, and leisure-time conditioning and non-conditioning physical activity as self-reported at 25 years of age

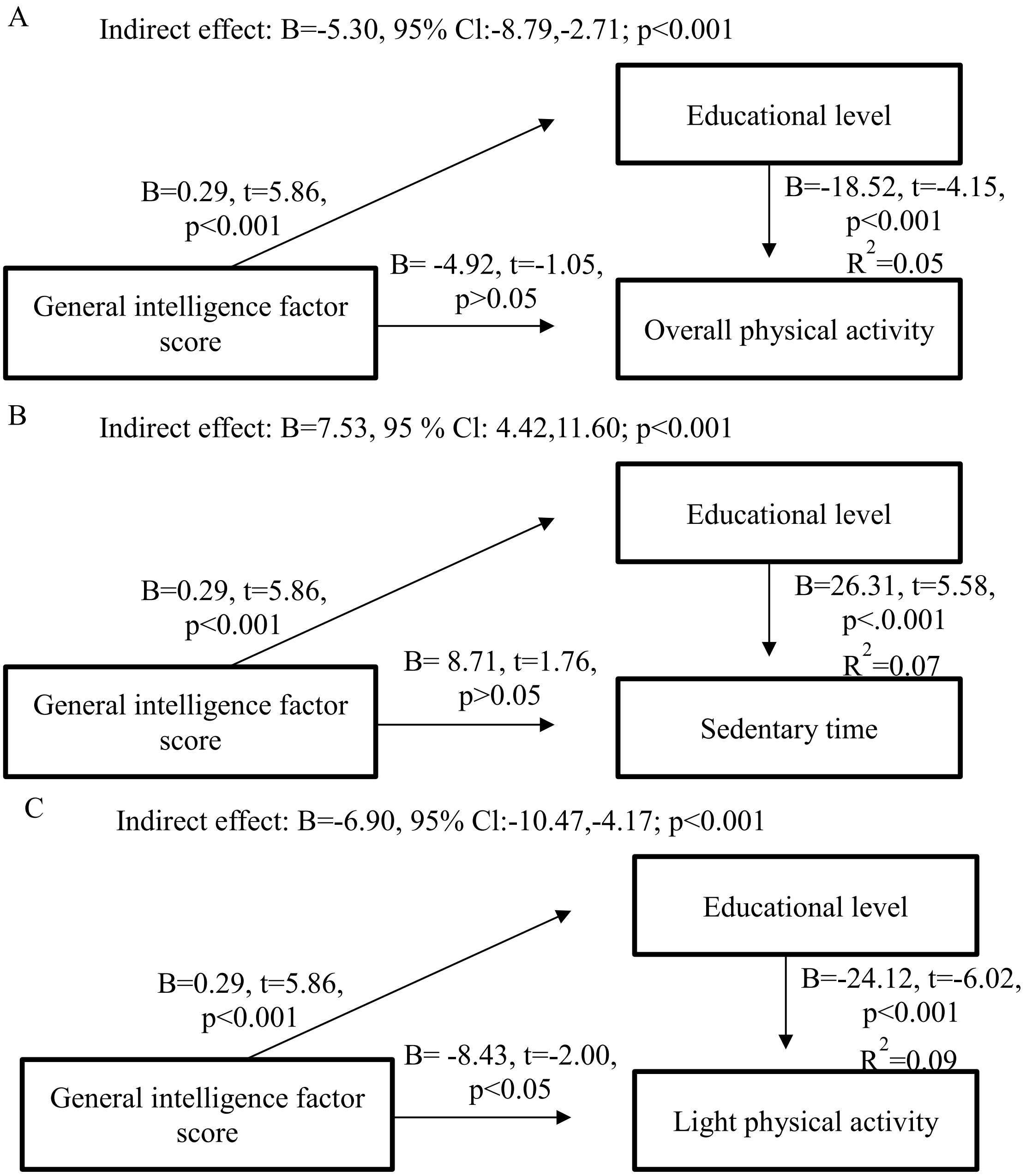
General intelligence factor score, change per one standard deviation	**Overall daily physical activity** CPM/day	**95% CI**	**P**
Occupational PA			
Mostly sitting	0.22	(-11.21, 11.65)	0.970
Quite a lot of walking, no lifting; Lot of walking and lifting; Physically very demanding work	-6.98	(-22.01, 8.04)	0.362
Commuting physical activity			
< 30 min	-12.31	(-24.53, -0.88)	0.048
≥ 30 min	-4.31	(-20.21, 11.58)	0.595
Leisure-time conditioning physical activity			
I read, watch TV and do tasks that do not demand much movement and do not cause physical strain; I walk, cycle, or perform other exercise not causing substantial perspiration at least 4 hours/week	-11.24	(-24.27, -1.80)	0.091
I exercise to maintain my physical condition for at least 3 hours/week; I regularly train for competitive sports for several times a week	-9.03	(-21.80, 3.73)	0.503
Duration of leisure-time non-conditioning physical activity			
<30min	-9.06	(-22.58, 4.46)	0.189
30 min to <60min	-12.44	(-26.29, 1.42)	0.079
60 min or more	5.91	(-18.39, 30.21)	0.633

Note. Values are derived from generalized linear models with normal reference distribution and adjusted for sex, age in adulthood, body mass index-for-age SD score at 56 months and mean of valid minutes of measurement period for PA. Abbreviations: CI=confidence interval; CPM=counts per minute.

Figure 1.


N=2,193
infants born between between March 15, 1985 and March 14, 1986 in the seven maternity hospitals in the county of Uusimaa, Finland (1,535 hospitalized and 658 not hospitalized within 10 days after birth)
56-month follow-up
N=1,737 (79.2%) participated
N=68 died, N=388 declined to participate or could not be traced
N=1,583 with valid data on cognitive abilities
N=139 did not undergo cognitive testing, N=15 with unreliable cognitive testing results
25-year follow-up
N=1,136 (59.4% of 1,913 invited) participated
N=107 no personal identification number, N=173 could not be traced/would have needed accommodation for overnight stay
N=676 with data on objectively measured physical activity
N=460 did not participate in physical activity monitoring
N=500 in analytic sample with 56-month follow-up data on cognitive abilities and 25-year follow-up data on objectively measured physical activity
N= 96 no 56-month follow-up data on cognitive abilities, N=74 no valid days on objectively measured physical activity at 25-year follow-up, N=6 with congenital malformations or chromosomal abnormalities excluded

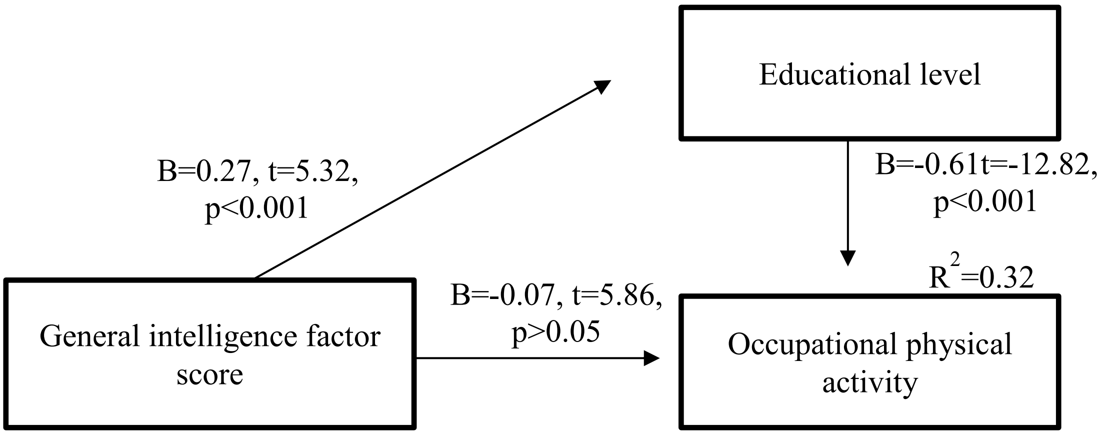
Supplementary figure 1.



Supplementary figure 2.

A

Indirect effect: B=-0.16, 95% Cl:-0.23,-0.10; p<0.001



B

Indirect effect: B=-0.03, 95% Cl:-0.06,-0.01; p<0.01