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Infant motor development and physical activity and sedentary time at midlife

Anna-Kaisa Karppanen[1,2] | **Tuula Hurtig**[3,4,5] | **Jouko Miettunen**[1,6] | **Maisa Niemelä**[7] | **Tuija Tammelin**[8] | **Raija Korpelainen**[1,2,6]

[1]Center for Life Course Health Research, University of Oulu, Oulu, Finland

[2]Department of Sports and Exercise Medicine, Oulu Deaconess Institute Foundation sr, Oulu, Finland

[3]PEDEGO Research Unit, Child Psychiatry, University of Oulu, Oulu, Finland

[4]Research Unit of Clinical Neuroscience, Psychiatry, University of Oulu, Oulu, Finland

[5]Clinic of Child Psychiatry, University Hospital of Oulu, Oulu, Finland

[6]Medical Research Center, Oulu University Hospital and University of Oulu, Oulu, Finland

[7]Research Unit of Medical Imaging, Physics and Technology, University of Oulu, Oulu, Finland

[8]LIKES Research Centre for Physical Activity and Health, Jyväskylä, Finland

Correspondence
Anna-Kaisa Karppanen, Center for Life Course Health Research, PO Box 5000, 90014 University of Oulu, Oulu, Finland.
Email: anna-kaisa.karppanen@oulu.fi

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This study investigated whether the timing of infant motor development is associated with self-reported and accelerometer-measured physical activity (PA) and sedentary time (ST) in midlife. This population-based study consisted of 4098 people born in 1966 in Northern Finland (NFBC 1966). Data on nine infant motor developmental milestones included making sounds, holding up the head, grabbing objects, turning from back to tummy, sitting without support, standing with support, walking with support, standing without support, and walking without support. At the age of 46, PA at leisure time and sitting time was self-reported. PA and ST were also measured with a wrist-worn Polar Active accelerometer that was instructed to be worn on the non-dominant hand 24 h/d for 14 days. A multiple linear regression analysis was used to analyze the association between infant motor development and PA and ST in midlife. Later infant motor development was weakly associated with higher accelerometer-measured light PA, but not with moderate-to-vigorous PA. Later infant locomotor development was associated with lower accelerometer-measured ST (β −0.07, $p = 0.012$) and lower self-reported sitting time at work (β −0.06, $p = 0.004$) in women. In conclusion, later infant motor development was associated with higher light PA and lower sedentary time at middle age. PA is a multifactorial behavior influenced by various factors from early childhood to midlife. Further research is required before more general conclusions can be drawn.

KEYWORDS
accelerometer, early life, locomotor development, middle-aged

1 | INTRODUCTION

Physical activity (PA) is one of the most important actions that people of all ages can engage in to improve their overall well-being.[1] PA fosters normal growth and development; improves daily functioning, quality of life,[2] and cognitive performance[3]; and reduces the risk of many chronic diseases.[4] Emerging evidence also indicates that excessive time spent engaging in sedentary behaviors, defined as any waking behavior performed in a sitting or lying posture with an energy expenditure of 1.5 or less metabolic equivalents (METs),[5] is a risk factor for premature mortality in all but the most physically active individuals who are active ≥1 h/d of moderate intensity PA.[6]

It has been suggested that many patterns of PA involvement are established early in life[7] and that the stability of PA is moderate to high along the life course from youth to adulthood.[8] During the first year of life, infants develop rapidly and achieve several developmental milestones, for example, sitting without support, standing with assistance, walking with assistance, standing alone, and walking alone.[9] Although children achieve particular milestones at a fairly wide range of ages, it is generally recognized that developmental milestones usually occur in a predictable sequence over time.[10] The skills developed during these milestones form the foundation for fundamental motor skills and PA.[9]

Previous studies have suggested that earlier motor skill development is associated with higher PA levels during an individual's preschool, childhood, and adolescent years[11,12]; however, less is known about the associations of early motor skill development with adulthood PA, and the evidence is inconclusive. For example, in a recent study of 34-year-old Finnish twins, earlier learning to stand unaided in infancy was associated with higher self-reported leisure-time PA (LTPA) in young adulthood,[13] whereas limited evidence was found between ages at reaching infant motor milestones and self-reported LTPA in adulthood in the study of 1946 British birth cohort.[14] Only two studies had examined the association between motor development and accelerometer-measured ST, and both were conducted in childhood, and the sample sizes were relatively small.[15,16] Both these studies found association between later motor development and higher ST in childhood. Studies on the Northern Finland Birth Cohort 1966 (NFBC) revealed several age-specific relationships. Infant motor development was associated with sports participation in adolescence,[12] as well as physical performance[17] and blood pressure[18] in adulthood.

In light of recent evidence, ST increases with age,[19] and studies with larger sample sizes and longer duration of follow-up are warranted to examine whether later achievement of developmental milestones acts as a predictor of sedentary behavior.[20] This population-based birth cohort study and design allowed us to investigate the associations between multiple infant motor milestones and self-reported and accelerometer-measured ST and PA with different intensity levels over a 45-year follow-up, enabling us to consider several confounding factors.

We aimed to examine whether the timing of infant motor development is associated with self-reported and accelerometer-measured overall PA and ST in midlife. We hypothesized that later achievement of developmental milestones is associated with lower levels of PA and with higher ST in midlife.

2 | MATERIALS AND METHODS

2.1 | Study design and participants

The NFBC 1966 is an ongoing longitudinal birth cohort of women and offspring collected at intervals from the provinces of Oulu and Lapland with an expected birth date in 1966 (n = 12,068 mothers and n = 12,231 children).[21] The cohort members have been carefully monitored prospectively from the prenatal period onward with interviews, questionnaires sent via the postal service, and clinical measurements. Follow-ups have been performed at the ages of 1, 14, 31, and 46. At the age of 46, the postal questionnaires including LTPA questions were mailed to all the participants (n = 10,321) whose addresses were known in 2012–2014 (response rate 66%, n = 6,851) (Figure 1). The questionnaires included items on health, health behavior, and socioeconomic background. Information on each participant's education, employment status, and prevalence of diagnosed diseases was obtained. Information on smoking history and alcohol consumption (g/d) was obtained based on multiple questions about drinking and smoking habits.

The present study population consisted of 4,098 (women 52.1%) individuals with measures of six or more early motor developmental milestones and appropriate data of either self-reported or accelerometer-measured PA and ST at the age of 46, see Figure 1. The study was reviewed and approved by the Ethical Committee of the Northern Ostrobothnia Hospital District, Oulu, Finland (94/2011). The study participants provided their written informed consent for the study.

2.2 | Infant motor development

Data on the age of reaching the main developmental milestones in the first year were gathered during regular visits to the Finnish child welfare clinics by nurses and doctors interviewing the parents and observing the

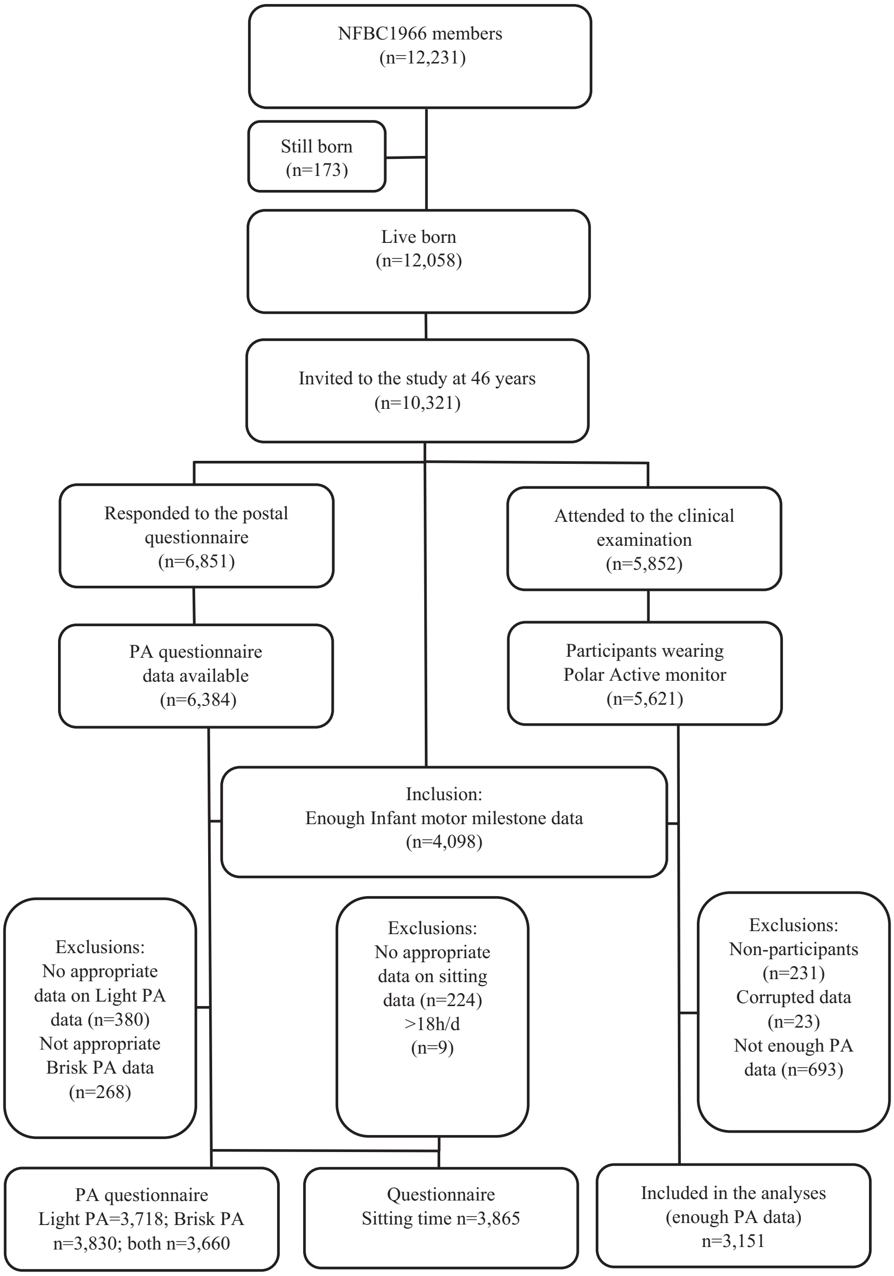

FIGURE 1 Northern Finland Birth Cohort 1966 (NFBC 1966) study population

child during infancy and early childhood in monthly intervals during 1966–1967. This is a routine procedure in Finnish public health care, and the protocol was not organized for study purposes. Thereafter, the data were retrospectively completed as previously described.[18] The following milestones were addressed: making sounds, holding up the head, grabbing objects, turning from back to tummy, sitting without support, standing with support, walking with support, standing without support, and walking without support. The achievement times, in months, of separate developmental milestones were assessed for each infant and recorded on a separate chart. In case the infant did not meet a developmental milestone by 14 months, the number of the month was written in numerical form.

2.3 | Self-reported LTPA and sitting time

Participation in LTPA was self-reported with the following question: how often and for how long do you participate in light and brisk physical activities/exercises during leisure time.[22] Brisk PA was described to cause at least some sweating and breathlessness, while light PA was defined causing no sweating or breathlessness. PA frequency had six response options: (1) once a month or less often, (2) 2–3 times a month, (3) once a week, (4) 2–3 times a week, (5) 4–6 times a week, and (6) daily. PA duration had the following response options: (1) not at all, (2) less than 20 minutes, (3) 20–39 minutes, (4) 40–59 minutes, (5)1–1.5 hours, and (6) more than 1.5 hours.[23] The weekly averages of MET-minutes of light and brisk PA were calculated by multiplying the PA volume (duration*frequency) by its intensity (light PA 3 METs and brisk 5 METs).[24]

Previously, it was reported in the same study population that the association between self-reported LTPA (MET-minutes) and accelerometer-measured MVPA was significant but relatively low ($r = 0.296$, $p < 0.001$),[25] and the question on the frequency of MVPA has been shown to be strongly associated with measured cardiorespiratory fitness at the age of 31 years.[26]

Sitting time was determined with the question "How much time do you spend sitting on a normal weekday?" The responses were divided to describe the amount of sitting in five domains such as work, at home and watching TV, at home in front of the computer, in a vehicle, and in another place.[27] This kind of question that assesses structured weekday sitting in different contexts has shown acceptable measurement properties.[28] The average daily sitting time (min/d) was calculated as the sum of durations of these sedentary behaviors. Those responding total sitting time higher than 18 h/d were excluded from analyses concerning sitting time (n = 9).

2.4 | Accelerometer-measured PA and ST

At the age of 46, the study participants' PA was measured using the wrist-worn waterproof accelerometer (Polar Active, Polar Electro Ltd, Kempele, Finland). Polar Active provides daily PA based on estimated MET values for every half minute using background information (body height, body weight, age, and gender).[29] Polar Active has been shown to explain well of the variation of double-labeled water technique during daily living (78%) and training period (62%).[30] The participants were instructed to wear the activity monitor 24 h/d for 14 days on their non-dominant hand. The accelerometers were blinded, not showing measured information to the user. The activity monitors were given to the participants (n = 5861) during clinical examinations, and they were instructed to mail them back after the measurement period. The intensity of PA was defined by using MET values and divided into ST and four levels of PA: ST (1–1.99 MET), light PA (2–3.49 MET), moderate PA (3.5–4.99 MET), vigorous PA (5–7.99 MET), and vigorous+PA (≥8 MET). The term "moderate-to-vigorous physical activity" (MVPA) corresponds here to all activity higher than 3.5 METs and total PA higher than 2 METs.[31] In our earlier comparison of different accelerometry-based methods, the threshold <2 MET for Polar Active provided similar results as threshold <100 cpm for ActiGraph, and the mean difference between the methods was 7.0 min/d (95% confidence interval from −17.8 to 31.7 min/d).[32] The participants with at least four valid days were included in the analyses, and the daily averages of duration spent in five activity levels (min/d) were calculated. The criteria for valid days were defined as at least 600 min/d monitoring time during waking hours.[33]

2.5 | Other variables

The following variables were considered as potential confounders and included as covariates in the analyses of the PA levels and ST: sex, birth weight, social status of the father at birth, body mass index (BMI), the level of education, strenuousness of work, and smoking habits at the age of 46 years.

Birth weight was measured immediately after birth by midwives and provided in kilograms and was rounded to the nearest 100 g.[21] The social status of the father at birth of the study participants was collected by a self-report questionnaire and classified into four categories: (1) professionals, (2) skilled workers and farmers with large ranches, (3) unskilled workers, and (4) small-area farmers.[12]

Body mass index at 46 years was based on the measurements at the clinical examination and was calculated as weight (in kilograms) divided by height (in meters) squared (kg/m^2). The education level of the participant at the age of 46 was classified into the following categories: (1) tertiary (university and polytechnic degree), (2) secondary (vocational or college level education), and (3) basic (vocational course or no education). The employment status was categorized into two types: (1) employed and (2) student, unemployed, retired, or other.

The physical strenuous of the work at 46 was calculated using multiple questions about tasks and postures of participant's work. We summed the recorded answers of nine questions and also divided the scores into two groups, using the median as cutoffs (1) light work and (2) strenuous work.[34]

Smoking status and habitual alcohol consumption (g/d) at 46 years were based on multiple questions concerning drinking and smoking habits. Smoking was categorized as (1) non-smoker (non-smoker or former smoker) and (2) current smoker. Alcohol consumption was categorized as (1) other (abstainers or moderate drinkers [≤20 and ≤40 g/d for women and men] and (2) heavy drinkers [>20 and >40 g/d for women and men]).[35]

Perceived health was queried with the question "How would do you evaluate your general health at the moment?" with five options (excellent, good, moderate, poor, and very poor). The options were further grouped into two classes: good (excellent and good) and other (moderate, poor, very poor).[36]

2.6 | Statistical analyses

The rate of missing data on individual milestones varied from 8.9% (walking with support) to 47.9% (capable of standing).

The missing values of the milestones were imputed by multiple imputing (MI) with 10 different data sets,[37] where the missing values were predicted based on non-missing milestone values. The values were imputed only if three or less of the total nine values were missing. The method of imputation was a Markov chain Monte Carlo (MCMC), which means fully conditional specification.[37] This method is suitable for data with an arbitrary pattern of missing values.[37] The MI model type for milestone scores was linear regression. Linear regression analyses were run across 10 imputed data sets.

A principle component analysis (PCA) was used to form combination variables of nine infant motor developmental milestones. PCA is a data reduction technique describing the variance in a set of variables into fewer dimensions.[38] The first principal component (locomotor score) was mostly driven by six later milestones such as turning from back to tummy, sitting without support, standing with support, walking with support, standing without support, and walking without support. The second component (non-locomotor score) was driven by the three earlier milestones (making sounds, holding up the head, and grabbing objects). Higher score indicated later motor development. In the PCA, the eigenvalue was set as >1. In men, the first factor had an eigenvalue of 3.67 with 40.8% of explained variance, and the second had an eigenvalue of 1.64 with 18.2%. Communalities ranged between 0.35 and 0.78. In women, the first eigenvalue was 3.93 with 43.7% of explained variance, and the second eigenvalue was 1.52 with 16.8% of explained variance. Communalities ranged between 0.34 and 0.79.

The characteristics of the samples and PA at 46 years were presented as frequency distributions for categorical variables, means, and standard deviations (SD) for normally distributed continuous variables and medians and 25th and 75th percentiles for variables with skewed distributions.

Sex differences were analyzed using the independent *t* test or the Mann–Whitney *U* test for each of the scale variables and the Chi-squared test for the categorical variables. The relationships between continuous variables were analyzed using either Pearson's or Spearman's correlation.

To analyze the statistical significance of the association between selected variables and main outcomes (self-reported and accelerometer-measured PA and ST), a multivariable linear regression was used. Skewed dependent variables were log- or square root-transformed to normalize the distribution. A multivariable analysis was performed separately for non-locomotor and locomotor scores to examine their association with the several outcome variables. The final models included all predictors associated with the outcome at $p < 0.10$ in the univariate analysis and remained significant at that level after multivariable adjustment.

Model 1 was adjusted for sex. Model 2 was further adjusted for potential early-life factors: birth weight, and social status of the father at birth. Model 3 was additionally adjusted for potential adult mediators: education level, BMI, strenuousness of work, and smoking at 46 years. No significant collinearity between independent variables was present in the final models (VIF < 2). The missing data for each covariate are presented as the variation in the number of subjects in the results. The variation in the number of subjects in the analyses was reported in the results. Probability values of $p < 0.05$ were used to determine statistical significance. All the statistical analyses were performed using IBM SPSS Statistics version 24.

3 | RESULTS

The characteristics of the study population in midlife are presented in Table 1. The study population consisted of 1964 (47.9%) men and 2134 (52.1%) women. The mean age of the participants in the present study was 46.6 (SD 0.6) years. The majority of the participants were employed (3252/87.8%), non-smokers (2964/77.1%), and moderate drinkers of alcohol or abstainers (3514/90.1%); had at least secondary-level education (3490/92.2%); perceived their health as good at 46 years (2546/65.7%). The mean BMI of the participants was 27.0 (SD 4.9).

The mean age of motor milestone achievement and the early life characteristics of the participants are presented by sex in Table S1. Almost all the participants achieved motor milestones within the normal WHO age ranges.[10] Using the WHO windows of milestone achievement as reference,[10] approximately 3% of the participants were unable to sit without support at 8 months, 0.3% were unable to walk without support at 18 months, and 0.1% experienced delayed achievement of walking with support and standing without support. Men achieved walking with support and were capable to stand slightly earlier than women ($p = .001$); however, no sex differences existed in other milestones or early-life factors.

At 46 years, complete PA questionnaire was filled by 3660 (1713 men and 1947 women) participants and sitting-time questions were answered by 3865 (men 1823 and women 2042) participants. Women reported more total PA (MET-min/wk) than men (825 [375–1500] vs 680 [225–1350], $p < .001$) and an hour less daily sitting time than men ($p < .001$) (Table 2). A total of 3151 (1450 men and 1701 women) participants provided valid accelerometer data. The average wearing time during the waking hours was 16 (SD 1.0) h/d. No significant difference between sex in accelerometer-measured total amount of PA was observed. However, women had more light PA (min/d) than men [288 (73) vs 266 (70), $p < .001$], whereas men spent more time in MVPA (min/d) than women [79 (39) vs 60 (29), $p < .001$]. Furthermore, men spent more time (min/d) in accelerometer-measured ST than women [645 (97) vs 623 (86), $p < .001$] (Table 2).

TABLE 1 Characteristics of the Northern Finland Birth Cohort 1966 study population at the age of 46 years (n = 4098)

Characteristics	Men n = 1964	Women n = 2134	All n = 4098	p-value
Age, years, mean (SD)	46.7 (0.7)	46.6 (0.6)	46.6 (0.6)	**<.001**
Height (cm), mean (SD)	178.6 (6.2)	164.8 (6.0)	171.2 (9.2)	**<.001**
Weight (kg), mean (SD)	87.8 (15.3)	72.4 (15.0)	79.5 (17.0)	**<.001**
BMI, (kg/m^2), mean (SD)	27.5 (4.4)	26.6 (5.4)	27.0 (4.9)	**<.001**
WC, (cm), mean (SD)	98.0 (12.0)	87.6 (13.3)	92.4 (13.7)	**<.001**
Educational level at 46, n (%)				**<.001**
Tertiary	417 (23.1)	607 (30.6)	1024 (27.1)	
Secondary	1201 (66.6)	1265 (63.9)	2466 (65.2)	
Basic	185 (10.3)	109 (5.5)	294 (7.8)	
Employment status, n (%)				.822
Employed	1536 (88.0)	1716 (87.7)	3252 (87.8)	
Other	210 (12.0)	240 (12.3)	450 (12.2)	
Smoking, n (%)				**<.001**
Non-smoker	1348 (74.3)	1616 (79.7)	2964 (77.1)	
Current smoker	466 (25.7)	412 (20.3)	878 (22.9)	
Alcohol consumption				
g/d, md (IQR)	8.7 (2.4, 22.3)	3.0 (0.6, 8.4)	5.0 (1.1, 14.5)	**<.001**
Heavy drinker, n (%)	212 (11.5)	173 (8.4)	385 (9.9)	**.001**
Perceived health, n (%)				.086
Good	1178 (64.3)	1368 (66.9)	2546 (65.7)	
Other	654 (35.7)	676 (33.1)	1330 (34.3)	

Note: Significant results ($p < .05$) are indicated in bold.

Abbreviations: BMI, body mass index; IQR, interquartile range; MD, median; SD, standard deviation; WC, waist circumference.

3.1 | Motor development and self-reported and accelerometer-measured PA

Sex-adjusted analyses showed that higher infant locomotor score (indicating later infant locomotor development) was positively and with borderline statistical significance associated with accelerometer-measured light PA and total PA in adulthood; nevertheless, these associations did not remain significant after the model was adjusted for adult variables (Table 3, model 3). When analyzed separately by sex (Table S2 and S3), this positive association between later locomotor development and higher light PA at 46 years remained statistically significant only in women after the model was adjusted for birth weight, social status of the father at birth, education level, and BMI (*B* 4.46 [0.91, 8.01], $p = .014$). Most of the covariates were also independently associated with the light PA in women. Higher birth weight (β 0.10, $p < .001$), lower social status of the father at birth (β −0.07, $p = .004$), lower education level at 46 years (β −0.22, $p < .001$) and lower BMI at 46 years (β −0.16, $p < .001$) were associated with higher light PA. When the model was also adjusted for strenuousness of work at 46 years, the positive association between locomotor development and light PA weakened, but remained of borderline significance (*B* 3.83 [0.11, 7.54], $p = .044$), in women (Table S2). Physically strenuous work was positively associated with light PA (β 0.31, $p < .001$). Women with physically strenuous work had higher light PA (min/d) compared to women having lighter work [319 (72) vs 265 (62), $p < .001$]. The association between infant motor development and accelerometer-measured MVPA did not reach statistical significance. Infant locomotor development was not associated with the self-reported PA.

3.2 | Motor development and self-reported sitting time and accelerometer-measured ST

The univariate analysis showed that later achievement of infant locomotor development was associated with lower self-reported sitting time and accelerometer-measured

TABLE 2 Self-reported and accelerometer-measured physical activity (PA) and sedentary time (ST) among Northern Finland Cohort 1966 study population at 46 years (n = 4098)

Variable	Men n = 1964	Women n = 2134	All n = 4098	*p*
Self-reported leisure-time PA and total sitting time, median (25th, 75th percentile)				
Light PA, min/wk	75 (30,210)	113 (50,210)	113 (30,210)	**<.001**
Brisk PA, min/wk	75 (15,188)	75 (23,188)	75 (15,188)	**<.001**
Total PA (Light and Brisk PA), min/wk	188 (65,338)	225 (108,390)	210 (90,375)	**<.001**
Total PA, MET-min/wk	680 (225,1350)	825 (375,1500)	780 (315,1418)	**<.001**
Total sitting time, min/d	480 (320,600)	420 (270,570)	458 (300,600)	**<.001**
Accelerometer-measured PA and ST, mean (SD)				
Light PA, min/d	266 (70)	288 (73)	278 (72)	**<.001**
MVPA, min/d	79 (39)	60 (29)	69 (35)	**<.001**
Total PA (light PA and MVPA), min/d	345 (94)	348 (86)	347 (90)	.297
ST, min/d	645 (97)	623(86)	633 (92)	**<.001**

Note: Significant results ($p < .05$) are indicated in bold.

ST, Total sedentary time; MVPA, Moderate to vigorous physical activity; MET, Metabolic equivalent of task.

ST. Both these associations attenuated, but self-reported sitting time remained statistically significant after adjustment for sex, social status of the father at birth, and BMI, education level, strenuousness of work and smoking habit at 46 years (Table 4). When analyzed separately by sex, there was no statistically significant association between infant locomotor development and accelerometer-measured ST and self-reported total sitting time in men (Table S4), whereas in women, the relationship remained significant also after adjustments (β −0.07, p = .012) (Table S5). Most of these covariates were independently associated with higher ST; lower birth weight (β −0.11, p < .001), higher level of education at 46 years (β 0.12, p < .001), higher BMI at 46 years (β 0.24, p < .001). Physically strenuous of work was associated with less accelerometer-measured ST (β −0.31, p < .001); women with physically strenuous work had 61 min/d less accelerometer measured ST compared to women with light work (590 [86] vs 651 [76], p < .001).

Association between infant locomotor development and self-reported sitting time weakened after adjustment for BMI at 46 years, education level, strenuousness of work, and smoking habit at 46 years in women (β −0.05, p = .030) (Table S5). When considering only self-reported sitting at leisure time at 46 years, the association with infant locomotor development was no longer statistically significant (p = .815), while the association between later locomotor development and lower self-reported sitting time at work remained significant in women after adjustments (β −0.06, p = .004). Infant non-locomotor development was not associated with the self-reported sitting time or accelerometer-measured ST.

4 | DISCUSSION

This large population-based birth cohort study evaluated the association between the timing of infant motor development and both self-reported and accelerometer-measured PA and ST in midlife. We found that later achievement of infant locomotor development milestones was significantly and positively associated with accelerometer-measured light PA in women although the associations weakened after adjusting the models with adulthood lifestyle variables. Few studies have examined the association between infant motor development and adult PA.[13,14] Our findings are in accordance with a previous longitudinal study[14] that found limited evidence of association between age at first standing and walking and LTPA from age 36 to 68. In that study, the authors used mother-reported information on ages at first standing and walking, and LTPA was only self-reported.

Since we found no association between infant locomotor development and self-reported LTPA, we suggest the part of the association between infant locomotor development and accelerometer-measured light PA might be due to the participants' education level and physical strenuousness of the work. Physically demanding work was less common in higher than lower educated group in both sexes. Self-reports in this study only considered PA at leisure time, whereas accelerometer measurement also captures PA garnered throughout the working day.

We found a weak inverse association between infant locomotor development and middle-age sedentary behavior based on both self-reported and accelerometer-measured data. When analyzing men and women separately, these

TABLE 3 Association between infant motor development (higher score indicating later development) and self-reported and accelerometer-measured physical activity (PA) according to multivariable linear regression analyses among Northern Finland Birth Cohort 1966 study population at 46 years (n = 4098)

	Model 1			Model 2			Model 3		
Variable	***B***	**β**	**95% CI**	***B***	**β**	**95% CI**	***B***	**β**	**95% CI**
Self-reported leisure-time PA									
Light PA, min/wk									
Non-locomotor score	0.05	0.01	−0.17 to 0.26						
Locomotor score	0.02	0.00	−0.19 to 0.23						
Brisk, min/wk									
Non-locomotor score	−0.07	−0.01	−0.27 to 0.13						
Locomotor score	−0.05	−0.01	−0.24 to 0.14						
Total PA (Light and Brisk PA), min/wk									
Non-locomotor score	0.01	0.00	−0.25 to 0.27						
Locomotor score	−0.01	0.00	−0.25 to 0.24						
Accelerometer-measured PA									
Light PA, min/d									
Non-locomotor score	0.74	0.01	−1.95 to 3.42						
Locomotor score	2.88	0.04	0.37 to 5.39*	2.76	0.04	0.21 to 5.30*	1.10	0.02	−1.60 to 3.81
MVPA, min/d									
Non-locomotor score	0.00	0.00	−0.07 to 0.07						
Locomotor score	0.00	−0.00	−0.07 to 0.07						
Total PA (Light and MVPA), min/d									
Non-locomotor score	0.64	0.00	−2.72 to 4.00						
Locomotor score	3.98	0.04	−0.08 to 6.22	3.98	0.04	0.75 to 7.21*,†	2.17	0.02	−1.21 to 5.55†

Abbreviations: CI, Confidence Interval; Model 1, Adjusted with gender; Model 2, Adjusted with gender and social status of the father at birth; MVPA, Moderate to vigorous physical activity.

**p*-value < .05; Separate models were run for non-locomotor and locomotor scores, *B* refers unstandardized regression coefficient, β refers standardized regression coefficient.

†Adjusted also with birth weight; Model 3 – Adjusted with gender, social status of the father at birth, body mass index at 46 y, education level, strenuousness of work and smoking at 46 y; Adjusted also with birth weight.

associations were no longer statistically significant in men; however, the trend of estimates remained the same. Our finding regarding the association between later achievement of locomotor development and lower accelerometer-measured ST might be partially explained by the fact that in our data later achievement of locomotor score was also associated with lower education level at 46 years and there were slightly more women with tertiary-level education than men. Few studies have examined the association between infant motor development and accelerometer-measured ST, and most of these studies were conducted in childhood. Aoyama et al.[15] found an association between later timing of independent walking and higher ST in childhood (n = 388); the ST data for that study were obtained using a triaxial accelerometer worn for seven consecutive days. Wijtzes et al.[16] examined the association between gross motor development and PA and ST in two-year-old toddlers (n = 347), and they found an association in the crude analysis between later motor development and higher ST. However, this association failed to remain significant after adjusting sex, age, number of siblings, and season. The sample sizes in both these studies were relatively small. It may be that motor development is a more relevant predictor of ST in childhood than in midlife when considering that ST tends to increase with age.[19] Nevertheless, PA behavior is complex, and it is also choice-driven. Multiple factors can enable or hinder individuals in their efforts to make healthy choices.

Previous evidence suggests that earlier development is associated with a higher level of education[39] and adult intelligence.[40] It is well-known that intellectually challenged or white-collar jobs have high amounts of ST.[41,42] Moreover, a recent study of young Finnish adults demonstrated that high education level was associated with high ST and lack of light PA.[43]

TABLE 4 Association between infant motor development (higher score indicating later development) and self-reported total sitting time and accelerometer-measured sedentary time (ST) according to multivariable linear regression analyses among Northern Finland Birth Cohort 1966 study population at 46 years (n = 4098)

	Model 1			Model 2			Model 3			
Variable	***B***	**β**	**95% CI**	***B***	**β**	**95% CI**	***B***	**β**	**95% CI**	**Adj. R^2**
Self-reported total sitting time, min/d										
Non-locomotor score	−0.04	−0.01	−0.20 to 0.13							
Locomotor score	−0.30	−0.06	−16.86 to −4.53**	−0.27	−0.06	0.43 to −0.12**	−0.17	−0.04	−13.38 to −0.50*	0.30
Accelerometer-measured ST (1–1.99 MET-min/d)										
Non-locomotor score	−1.79	−0.02	−5.24 to 1.67							
Locomotor score	−4.70	−0.05	−7.91 to −1.49**	−4.93	−0.05	−8.24 to −1.63**,†	−3.49	−0.04	−6.98 to −0.00†,‡	0.18

Note: Separate models were run for non-locomotor and locomotor scores, *B* refers unstandardized regression coefficient, β refers standardized regression coefficient.

Abbreviations: CI, Confidence Interval; MET, Metabolic equivalent of task; Model 1, Adjusted with sex; Model 2, Adjusted with sex and social status of the father at birth; Model 3, Adjusted with sex, and social status of the father at birth, body mass index, education level and strenuousness of work at 46 years.

*$p < .05$.

**$p < .01$.

†Adjusted also with birth weight.

‡Adjusted also with smoking at 46 years.

Since prolonged ST is recognized as a risk factor for chronic disease and mortality,[4,6] individualized interventions are warranted to increase PA levels and to reduce the amount of ST. In our study, women had less ST and less MVPA; however, they spent more time engaged in light PA compared to men. These findings are consistent with other studies that used the objective measures of PA among young adults[43] and older adults.[44]

This study has some limitations. There may be unobserved confounding factors associated with both infant motor development and adulthood ST or PA that were not included in the analyses. Such factors could be psychological (motivation, beliefs, self-efficacy) and social environmental (parenting style, behavioral modeling) factors.[45] Contradicting findings may also arise from methodological differences in data collection and sample size, use of different devices (e.g., different PA measurement technologies), and variation in adjustment for confounders.

Our study may have lacked power to detect stronger association because of relatively narrow variation in infant motor development, and individuals who are more physically active may have participated in the study in adulthood. Nevertheless, nurses and doctors at the Finnish child health clinics assess the physical, mental, and social condition of the children, and multi-professional support is provided for the families if needed. At least nine visits to a child health clinic are scheduled for the first year of a child's life in Finland. It is possible that during these checkups, preventive interventions might have started in the case of lateness in children's milestones; unfortunately, data were not available. A key factor in monitoring change in stages of development is the time lapse between the observations.[10] In our study, following the standard protocol in Finnish healthcare, observations occurred in monthly intervals and achievement times of the developmental milestones were recorded in months. If the achievement times were collected in weeks, a more accurate information of the infant motor development would have been available. However, the standard procedure could not be changed for the study purposes. Contrary, strength of this research is the study of multiple milestones together since a delayed development of a single milestone has limited clinical value.

The most evident strength of the study is large population cohort and its prospective study design, which allowed us to examine the associations concerning infant motor development and PA and ST over the course of 46 years. The use of wrist-worn accelerometer over a 2-week period strengthens the internal validity of this study. Although wrist-worn accelerometers may provide more relevant information about PA, especially on ST and light intensity PA, than data based on questionnaires, they may underestimate the intensity of some activities such as bicycling and resistance training.

5 | PERSPECTIVE

In this population-based birth cohort study, later infant motor development was associated with higher light PA and lower ST. These relationships are influenced by other contextual factors such as education level and physically strenuousness of work. Further research is needed to identify factors directly or indirectly associated with PA, sedentary behavior, or behavioral change toward a physically active lifestyle.

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CONFLICT OF INTEREST

There is no conflict of interest related to the study.

AUTHOR CONTRIBUTIONS

We state the following author contributions: AKK, JM, TH, MN, and RK involved in literature search; RK, JM, and TH contributed to study design; RK, JM, MN, and TT collected the data; AKK, JM, TH, TT and RK analyzed the data; AKK, JM, TH, TT, and RK involved in data interpretation; and AKK, JM, TH, TT, MN, and RK involved in writing. All authors have read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the Northern Finland Birth Cohort (NFBC) for researchers who meet the criteria to access confidential data. Please contact the NFBC Project Center (NFBCprojectcenter@oulu.fi) and visit the cohort Web site (Northern Finland Cohorts http://www.oulu.fi/nfbc/) for more information.

ORCID

Anna-Kaisa Karppanen https://orcid.org/0000-0001-9670-1247
Maisa Niemelä https://orcid.org/0000-0002-1008-3263

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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