European Journal of Pediatrics (2025) 184:65
https://doi.org/10.1007/s00431-024-05902-y

BRIEF REPORT

Age- and sex-specific reference percentile curves for accelerometry-measured physical activity in healthy European children and adolescents

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Received: 23 July 2024 / Revised: 18 November 2024 / Accepted: 22 November 2024

Abstract

Physical activity measured by accelerometry (PA-accelerometry) is used as an indicator of physical capacity in chronic diseases. Currently, only fragmented age ranges of reference percentile curves are available for European children and adolescents. This study aimed to provide age- and sex-specific percentiles for physical activity measured by hip-worn accelerometry derived throughout the full age range of European children and adolescents. Individual-level population-based PA data measured by accelerometry from HELENA and IDEFICS/I.Family studies were pooled and harmonized. Together these studies involved children and adolescents aged 2–18 years from 12 European countries. Primary outcomes included averaged counts per minute (CPM), sedentary time (SED), light PA (LPA) and moderate-to-vigorous PA (MVPA). Generalized Additive Models for Location, Scale and Shape were used to derive age- and sex-specific reference percentile curves for these outcomes. The combined cohort consisted of 11,645 children and adolescents aged 2 to 18 years who contributed 14,610 valid accelerometry recordings, with a median accelerometer wear time of 6 days. This dataset allowed for the construction of age- and sex-specific reference percentile curves for CPM, SED, LPA, and MVPA. The curves demonstrated varying trends and variability across age groups.

Conclusions: This study provides age- and sex-specific percentile curves for PA-accelerometry in European children and adolescents, addressing a current gap in the availability of full-age range reference data. These curves based on healthy children and adolescents can be used by clinicians, researchers, and policymakers to interpret PA-accelerometry measurements, track physical activity trends, and evaluate treatment responses and health interventions.

What is Known:

- *Daily physical activity (PA) is considered an important measure in various paediatric conditions. Existing reference data for PA in European children based on hip-worn accelerometers are limited to specific age ranges, and comprehensive data covering the full age range are lacking.*

What is New:

- *The study provides age- and sex-specific reference curves for PA derived by hip-worn accelerometers in European children and adolescents. These curves aid clinicians, researchers, and policymakers in interpreting PA measurements and tracking trends over time in European children.*

Keywords Accelerometer · Adolescents · Children · Percentile curves · Physical activity

Communicated by Gregorio Milani

Extended author information available on the last page of the article

Published online: 05 December 2024

Introduction

Background

In children, daily physical activity (PA) is considered an important measure in both health and disease [1]. Children's PA levels can be significantly affected by their health status. In chronic conditions that impair exercise tolerance, such as heart or lung diseases, PA measured by accelerometry (PA-accelerometry) has emerged as a valuable indicator of physical capacity, allowing for tracking over time [2–4]. In these cases, PA-accelerometry is also suggested as a clinically meaningful outcome to assess treatment responses or targeted interventions [3, 4]. On the other hand, in cardiometabolic conditions like obesity, dyslipidaemia and diabetes, PA can be considered a behavioural risk factor.

A specific challenge in tracking paediatric conditions is the age dependency of PA [5–7]. WHO guidelines set thresholds linking PA to health outcomes [1]. Normative reference curves complement these by showing the distribution of objectively measured PA in a reference population, accounting for substantial age and sex differences. These curves help clinicians compare an individual's activity to age- and sex-matched peers and track changes over time. Such data are particularly needed in paediatric populations, where European data are still fragmented [5–7].

Objective

The two major sources of European multinational paediatric population-based PA-accelerometry data collected using modern clinically validated accelerometers are as follows: (1) the 'Healthy Lifestyle in Europe by Nutrition in Adolescence' study (HELENA) [6], and (2) the 'Identification and prevention of Dietary- and lifestyle-induced health EFfects In Children and infantS' primary study and its follow-up study 'I.Family' (IDEFICS/I.Family) [7, 8]. Together these sources comprise healthy children > 2 years of age from 12 European countries, although the age ranges of the individual studies are fragmented. In view of the lack of full-age range European PA-accelerometry reference percentile curves, this study aimed to describe PA-accelerometry levels and to provide age- and sex-specific reference percentile curves for European children and adolescents based on a participant-level aggregation of HELENA and IDEFICS/I.Family.

Methods

Study design

We pooled and harmonized individual-level PA-accelerometry data from HELENA and IDEFICS/I.Family studies. The design and methodology of HELENA and IDEFICS/I.Family have been detailed elsewhere [6–8]. In short, HELENA was a multi-centre, cross-sectional study on diet and health-related parameters among children and adolescents aged 12.5–17.5 years, from nine European countries with data collection from 2006 to 2007 [6]. IDEFICS was a multi-centre, prospective cohort study on lifestyle and diet among children aged 2–11 years, from eight European countries [7]. The study consisted of assessments at baseline (T0, 2007–2008), a 2-year follow-up (T1, 2009–2010) and a mail survey (T2). The participants and their siblings were invited to attend the follow-up study I.Family from 2013 to 2014 (T3) [8]. During the follow-up study, Poland joined the cohort. In each country, the participating centres of both studies obtained approval from the local ethics committees. Participants or their parents provided written informed consent.

Study population

Healthy participants, i.e. reported to have no orthopaedic, musculoskeletal or rheumatic diseases, up to 18 years of age of HELENA and IDEFICS/I.Family who had accelerometry recording of at least 6 h on at least 2 weekdays and 1 weekend day were included. If an IDEFICS/I.Family-participant had multiple recordings from T0 to T3 all measurements were considered.

Accelerometry recordings

PA was measured using uni-axial or tri-axial accelerometers from the same vendor (ActiGraph LLC, Pensacola, Florida). Despite subtle model variations (ActiTrainer, GT1M, GT3X), all devices used in the studies consistently captured PA, ensuring data comparability between the source cohorts. According to the original protocols, participants were asked to wear the accelerometer on the hip during waking hours for at least 3 days (IDEFICS) or at least 7 days (HELENA/I.Family) and were removed during water related-activities. Data were integrated into 15 s epochs. To ensure that only valid episodes of wear time were included, we applied the Choi non-wear algorithm [9]. Valid accelerometry registrations were defined as at least 360 min valid wear time per day, with at least two weekdays and one weekend day after exclusion of non-wear time. Averaged uni-axial counts per minute (CPM), time spent sedentary (SED), time spent in light activity intensity levels (LPA) and time spent in moderate or vigorous PA-accelerometry intensity levels (MVPA) were used as accelerometer outputs. The Evenson cut-points were applied to define SED, LPA and MVPA [10]. While primarily validated for children aged 5–8, these cut-points are used for younger children as well, allowing consistency

in analyses across the full paediatric age range. Further details on used methods regarding collection and processing of accelerometry data have been detailed previously [6, 7].

Statistical analysis

The results are reported as number (percentage), median (interquartile range [IQR]) or mean (standard deviation [SD]), depending on the context and purpose of reporting. All statistical analyses were performed using R (version 3.6.2). The Generalized Additive Models for Location, Scale and Shape (GAMLSS) package (version 5.1–5) was used to generate the age- and sex-specific reference percentile curves [11]. To find an appropriate model for each PA-parameter, forward-backwards algorithms were used considering the normal, Box-Cox-Cole-Green, Box-Cox-*t*- and Box-Cox power exponential distributions. The distribution parameters were modelled as constant or with age as dependent variable (considered as penalized splines and linear function). The overall goodness of fit for each primary outcome was assessed by the Bayesian Information Criterion, (age-specific) worm plots (also to check for normality of residuals) and percentages of data below the percentile curves to choose a final model.

Results

Patient characteristics

A total of 14,610 accelerometry registrations were included: a list of participants per country and a flow chart are available as supplemental material (eTable 1 and eFig. 1). The age range was 2.0 to 17.9 years and 51% of the cohort was female. From HELENA, we included $N = 2{,}035$ observations. From multiple time-points of the IDEFICS/I.Family cohort, we included 12,575 observations of 9610 children (T0, 3991; T1, 4144; T3, 4440, < 22% of study participants with multiple measurements). The characteristics of study participants are presented in Table 1.

Accelerometry recordings

The device was worn for a median duration of 6 days (range 3–15 days), and the median wear time was 745 min per day (range 415–1408 min). The number of days and valid wear time were slightly higher in older participants. The number of recording days and valid wear time were essentially the same for boys and girls (eTable 2, supplement).

Physical activity reference percentiles

Figure 1 shows the reference percentiles curves for boys and girls for the four accelerometer outputs. The corresponding reference percentile tables including the age- and sex-specific distribution parameters (μ,σ,ν,τ) are available as supplement (eTables 3–10). The diagnostics plots and the selected modelling parameters for the final models are also available as supplement (eFigs. 2–3 and eTable 11). The percentile curves for CPM depicted in panels A/B of Fig. 1 demonstrate an inclining trend between the age of 2 and 5, a declining trend between the age of 5 and 13 years, followed by a stable course during early adolescence. The percentile curves for SED are depicted in panels C/D and demonstrate an inclining trend between the age of 2 and 14 years, followed by a stable course during early adolescence. The percentile curves for LPA are depicted in panels E/F and demonstrate a declining trend between the age of 2 and 14 years, which is particularly steep between 8 and 12 years, followed by a more stable course during early adolescence. The percentile curves for MVPA are depicted in panels G/H and demonstrate an inclining trend between the age of 2 and 7, a gradual declining trend between 7 and 14 years, followed by a relatively stable course during early adolescence.

Discussion

This study provides age- and sex-specific reference curves for PA-accelerometry in European children and adolescents, addressing a significant gap in existing data. As previously

Table 1 Characteristics of participants stratified by cohort

	IDEFICS: T0	IDEFICS: T1	I.Family: T3	HELENA	Total
	$N = 3991$	$N = 4144$	$N = 4440$	$N = 2035$	$N = 14{,}610$
Female, *n* (%)	1985 (49.7)	2100 (50.7)	2254 (50.8)	1108 (54.4)	7447 (51.0)
Age*, years	5.9 (2.0–9.9)	8.1 (2.5–11.8)	10.9 (2.2–17.9)	14.6 (12.5–17.4)	9.3 (2.0–17.9)
Wear time, min/day	712.8 (660.5–775.7)	722.3 (666.4–786.5)	773.6 (717.4–827.1)	797.2 (724.0–857.4)	745.0 (683.2–814.7)
Wear days, *n*	4 (4–5)	5 (4–6)	7 (6–7)	7 (6–7)	6 (4–7)

Data presented as number (percentage) or median (interquartile range), unless otherwise indicated. N indicates number of accelerometry registrations. *IDEFICS* identification and prevention of dietary- and lifestyle-induced health effects in children and infants, *HELENA* Healthy Lifestyle in Europe by Nutrition in Adolescence. T0, baseline; T1, first follow-up; T3, third follow-up; *Min* minutes. *Mean and minimum–maximum range reported instead of median and interquartile range

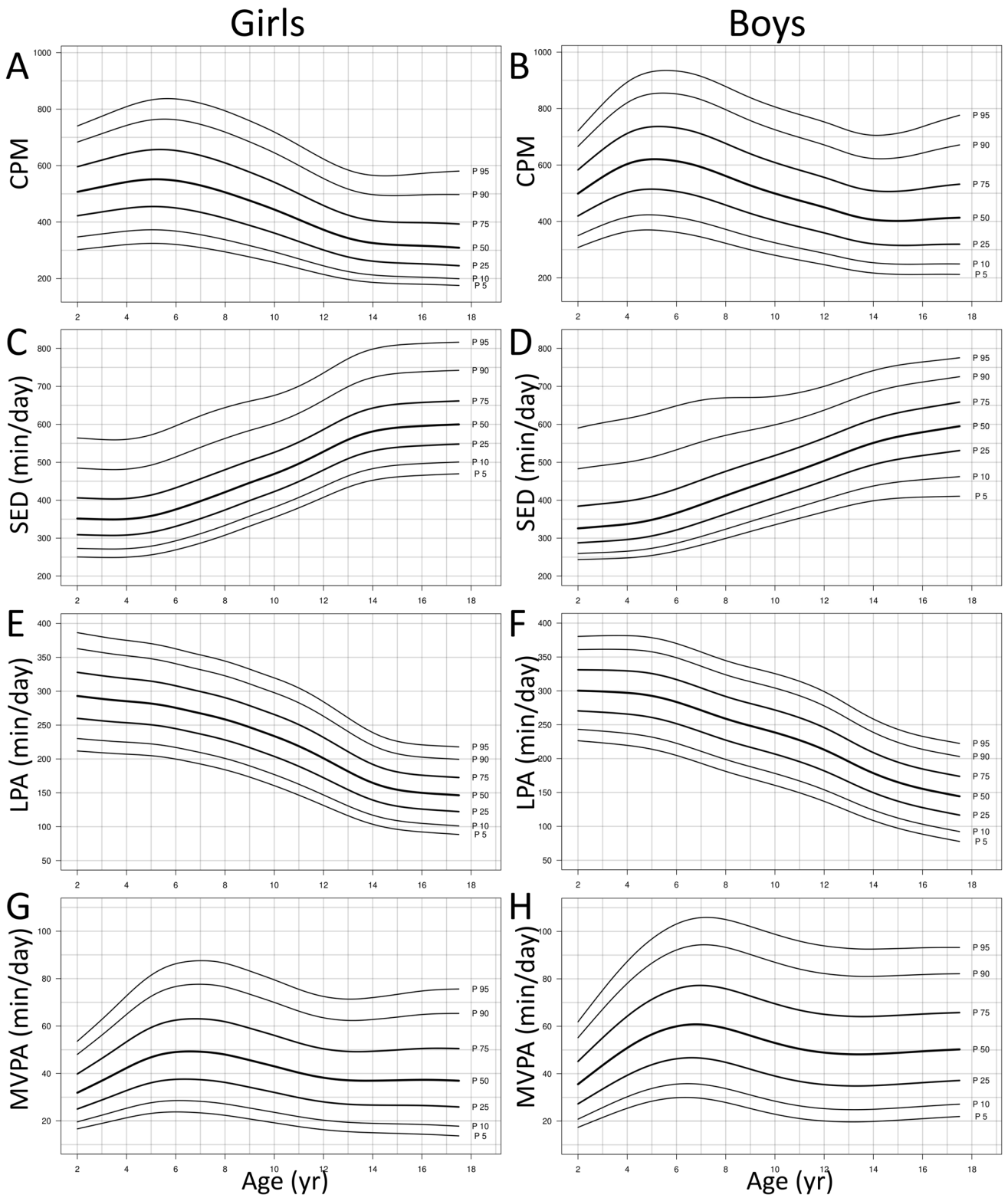

Fig. 1 Physical activity reference curves based on accelerometer outputs. **A** girls, counts per minute (CPM). **B** Boys, counts per minute (CPM). **C** Girls, sedentary time (SED). **D** Boys, sedentary time (SED). **E** Girls, light physical activity (LPA). **F** Boys, light physical activity (LPA). **G** Girls, moderate-to-vigorous physical activity (MVPA). **H** Boys, moderate-to-vigorous physical activity (MVPA). CPM, counts per minute. SED, sedentary time. LPA, light physical activity. MVPA, moderate to vigorous physical activity. Min/day, minutes per day. Yr, year

discussed, activity patterns in the current European cohorts align with age and sex trends reported in other geographical regions [5–7].

The curves and tables provided in this study may enable the assessment of children's PA relative to healthy peers, helping to identify deviations from typical activity levels. In conditions like heart and lung diseases, such deviations may reflect changes in exercise tolerance and disease severity [3, 4], while in cardiometabolic conditions, PA deviations provide insights into behavioural changes. From a public health perspective, these curves can track population-level PA trends, highlight at-risk groups and support the evaluation of PA promotion programs and public health interventions.

Strengths and limitations

This study includes a substantial representative cohort of 11,645 European children and adolescents across 12 countries. However, it naturally cannot fully represent the entire diversity of the European paediatric population. Data collection spanned from 2006 to 2014, encompassing a period marked by changes in lifestyle and technology that may have influence PA patterns. The use of a single set of absolute intensity-based cut-points may have introduced the potential for some misclassification of activity levels, particularly in the youngest and oldest age groups. However, this approach does not compromise the accuracy or generalizability of the reference curves. By applying a consistent set of cut-points across the entire age range, we ensured uniformity and avoided the inconsistencies that would result from using different cut-points for different age groups. Lastly, the reference curves are specific to *hip-worn* PA-accelerometry and presuppose the utilization of specific actigraphy settings, including device type, epoch size, and activity intensity cut-offs. Although the applied settings are most common in the field, this specificity is a potential constraint when applying the reference curves to different measurement approaches.

Conclusions

This study provides age- and sex-specific reference curves for hip-worn PA-accelerometry in European children and adolescents, filling a gap in reference data for the full-age range. These reference curves may serve as a valuable resource for clinicians, researchers and policymakers, facilitating the interpretation of PA-accelerometry measurements for the specific settings that are applied.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00431-024-05902-y.

Acknowledgements The present study includes data from the HELENA study and IDEFICS and consequent I.Family studies and is published on behalf of the corresponding European Consortia. The authors are very grateful to all the children, adolescents and parents participating in these studies. We also wish to thank the school boards, head teachers and communities for their support and the study nurses, interviewers, laboratory technicians and data managers for their effort.

Authors' contributions MP, LM, WA, RB, and TI were involved in the conception and design of this specific pooled study. CB, LM, LL, FL, SH, DM, MT, KK, MR, YP, YM, LB, KW, AP, KS, AK, SM, MG, JA, AM, FO, WA, and TI have been involved in the acquisition of data. MP, AS, WA, RB, and TI were involved in the analysis and/or interpretation of study data. All authors were involved in drafting the manuscript or revising it for critical content and read and approved the final manuscript.

Funding This work was supported by the European Commission within the Sixth RTD Framework Programme for the HELENA study (Contract No. 007034), for the IDEFICS study (Contract No. 016181) and within the Seventh RTD Framework Programme for the I.Family Study (contract no. 266044).

Data availability The data that support the findings of this study are available from the HELENA and IDEFICS/I.Family study groups upon reasonable request.

Declarations

Ethics approval All contributing studies have been approved by the appropriate ethics committees and have been performed in accordance with the ethical standards of the Declaration of Helsinki. The names of the approval committees/institutional review boards of HELENA were as follows: (1) Austria: Ethics Committee of the Medicine's University from Vienne; (2) Belgium: Ethics Committee of the Gent University Hospital; (3) France: Protection committees people from Lille; (4) Germany: Ethics Committee of the Medicine's University from Dortmund; (5) Greece: Ethics Committees of the Harokopio University from Athens and University of Crete School of Medicine from Heraklion; (6) Hungary: A Pecsi Orvostudomanyi és Egészségtudomanyi Központ Regionalis Kutatas-Etikai Bizottsaga from Pècs; (7) Italy: Ethics Committee of Medical Activities of the University of Naples Federico II; (8) Spain: Ethics Committee for Clinical Research of Aragon; (9) Sweden: Regional Ethics Committee from Stockholm. The names of the approval committees/institutional review boards of IDEFICS/I.Family were as follows: (1) Belgium: Ethics Committee of the Gent University Hospital; (2) Cyprus: Cyprus National Bioethics Committee; (3) Estonia: Tallinn Medical Research Ethics Committee; (4) Germany: Ethic Commission of the University of Bremen; (5) Hungary: Medical Research Council; (6) Italy: Ethics Committee of the Local Health Authority in Avellino; (7) Poland: Bioethical Committee of the University of Rzeszów; (8) Spain: Ethics Committee for Clinical Research of Aragon; (9) Sweden: Regional Ethics Research Board in Gothenburg.

Consent to participate All participants and/or their legal guardians have given informed consent prior to inclusion in the contributing studies.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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