1. Abstract

Background: Type 2 diabetes mellitus (T2DM) is a worldwide public health problem. Shared risk factors (e.g., low physical activity levels) between parents at risk and their children should be addressed to prevent the development of the disease. The aim of this study was to determine the association of objectively measured step counts per day between parents at risk of developing T2DM and their 6- to 10-year-old children.

Methods: Baseline data from the "Families across Europe following a Healthy Lifestyle 4 Diabetes prevention" (Feel4Diabetes-study) study were analyzed. Two hundred fifty dyads of children and one parent (54.4% girls and 77.6% mothers) from Belgium were included. Step counts per day during 5 consecutive days (3 weekdays and 2 weekend days) from parents and their children were objectively measured with ActiGraph accelerometers.

Results: Adjusted linear regression models indicated that parents' and children's step counts were significantly associated during all days (β=0.245), weekdays (β=0.205), and weekend days (β=0.316) ($p \leq 0.002$ in all cases). Specifically, mother-daughter associations during all days (β=0.294) and weekend days (β=0.418) ($p \leq 0.001$ in both cases) and father-son step counts during weekdays (β=0.422) and when considering all days (β=0.467) were significant ($p<0.02$ in both cases).

Conclusion: There is a positive association between step counts from adults at risk of developing T2DM and their children, especially in the mother-daughter and father-son dyads.

What is known

- T2DM is a worldwide public health problem.
- Parental physical activity practice may be reflected in their children.

What is new

- Associations between total steps per day of adults at risk of developing T2DM and their children are positive and significant, especially between mothers and their children.
- Adults at risk of developing T2DM have low compliance with current step count recommendations and so do their children.

Keywords: Type 2 Diabetes Mellitus, physical activity, parents, children

List of abbreviations in alphabetical order

BAz: z-Score of body mass index

BMI: Body Mass Index

Feel4Diabetes-study: Families across Europe following a Healthy Lifestyle 4 Diabetes prevention Study

FINDRISC: Finnish Diabetes Risk Score

PA: Physical Activity

T2DM: Type 2 Diabetes Mellitus

2. Text

1. Introduction

Type 2 diabetes mellitus (T2DM), long considered an uncommon and unperceived disease, is nowadays an important international public health problem and one of the major health challenges of the 21st century [1]. It can even be considered, along with obesity, as the greatest chronic disease epidemic in the history of humanity [1].

Family history of T2DM is an important risk factor for developing the disease, however, these genes seem to be able to account for 5-10% for T2DM and approximately 4% for obesity, which means that even though there is a genetic link to the inheritance of T2DM, epigenetics and the environment are also likely to interact to define the individual risk of disease [2]. Independent risk factors for the development of T2DM in adults include being over 45 years old, being overweight or obese, hypertension, or dyslipidemia and [3] other environmental factors such as the quality of diet, increased monitor viewing time, short or disturb sleep, smoking, stress, depression, low socioeconomic status and being physically inactive [4].

It must be acknowledged that there is an increased prevalence of T2DM in younger adults, and evidence is accumulating that young-onset T2DM has a more aggressive disease phenotype, leading to premature development of complications with adverse effects on quality of life [5]. Screening for prediabetes and T2DM with validated tools in adults is recommended to identify those at risk as soon as possible. Fortunately, once the risk for developing T2DM is established, the progression of T2DM is not inevitable, given that it can be prevented through lifestyle behavior changes, such as a healthy diet and sufficient levels of physical activity (PA) [6]. Therefore, the American Diabetes Association base their recommendations for adults at high risk of developing T2DM on modest lifestyle changes such as diet modifications and PA [7,8]. In terms of PA, an increase in total steps per day combined with other lifestyle changes, like making healthy reductions in total caloric and fat intake and reducing the consumption of sugar-sweetened beverages, can reduce the risk of T2DM through the loss of weight, changes in body composition, and positive changes in insulin sensitivity and utilization [9].

In this aspect, parents serve as important role models given that parental attitudes and behaviors regarding PA and nutrition can have a substantial positive or negative impact on the lifestyle behaviors of their children [10]. In a previous study in which families from Pennsylvania were identified according to dietary characteristics and PA of parents, it was shown that 5- to 7-year-old daughters from parents that reported low levels of PA had a significantly higher Body Mass Index (BMI). This shows that parental lifestyle is associated with children's health outcomes such as weight status [11]. A previous study from a rural community in the United States looking at the associations between parents' and children's steps per day showed that mothers' and fathers' steps per day were significantly and positively associated with children's steps per day ($p<0.02$). This means that parental PA behavior is associated with the PA behavior of their children [12].

Positive associations in PA levels between parents and their 6- to 11-year-old children have been observed when analyzing the number of steps reached on all days, on weekend days, and after 3:00 PM on weekdays [13]. Nevertheless, Brouwer et al. found that maternal PA was significantly related to PA in girls but not in boys, and that in fathers, PA levels were predominantly related to PA in their sons, concluding that interventions could focus on the PA of the parent of the same sex [14]. Similar results were found by Bringolf-Isler et al., with the exception that the association of mothers' and children's PA did not depend on the parent-offspring sex-match [15].

However, some opposite results have been found in a study conducted by Djafarian et al. in 2- to 6-year-old children and their parents, in which associations of PA between children and their parents were not significant except for morning activity, which was positively related to the mothers' morning activities [16]. The association between parental PA levels and PA levels of their children may be an important factor in the prevention of T2DM in the family environment, as studying it would allow us to identify noncompliance with recommendations and to motivate them to comply with current PA recommendations. Nevertheless, it remains unclear if PA levels of children from parents with a higher risk of developing T2DM are associated with their parents' PA levels.

Therefore, the present study aimed (I) to assess the association between step counts from parents with a higher risk of developing T2DM with their children's step counts on weekdays, weekend days, and the average of all days (3 weekdays and 2 weekend days), (II) to assess if there is an association between parents' and children's compliance with current step count recommendations and (III) to assess the sex-specific associations between steps per day in the following types of dyads: (a) mother-son, (b) mother-daughter, (c) father-son (d) father-daughter.

2. Materials and methods

2.1 Study design

Cross-sectional data from the "Families across Europe following a Healthy Lifestyle 4 Diabetes prevention" study (Feel4Diabetes-study) were analyzed for the present study (www.feel4diabetes-study.eu)[17]. The Feel4Diabetes-study is registered in the clinical trials registry: NCT02393872 (https://www.clinicaltrials.gov/ct2/show/NCT02393872). This project aimed to develop, implement, and evaluate a school- and community-based intervention to prevent T2DM among families from low- and middle-income countries and vulnerable populations in high-income countries in Europe. The participating countries from the Feel4Diabetes-study were Belgium, Bulgaria, Finland, Greece, Hungary, and Spain. Each center used the monitors they had available before conducting the study, and therefore, devices were different across countries. In order to obtain consistent results, valid objectively measured PA data from Belgium was used in this study because this was the center that collected most of the available data.

Longitudinal data collection was performed once per year between May 2015 and June 2018, while the data presented in this study correspond to the baseline survey carried out in 2015. Children attending the first 3 grades of primary school (7- to 10-year-old children) and their families were recruited in January 2015. Adults from participating families were classified into the "low-risk group" or the "high-risk group" according to the potential risk of developing T2DM estimated by the Finnish Diabetes Risk Score (FINDRISC), which is a simple, fast, inexpensive, noninvasive, and reliable tool to identify individuals at higher risk for T2DM in the next 10 years [18]. The FINDRISC includes questions regarding age, BMI, waist circumference, PA, fruit and vegetable consumption, use of medication for hypertension, hyperglycemia background, and family history of T2DM. Families with 1 or 2 adults that obtained a score $\geq$ 9 in the FINDRISC were classified as "high-risk families."

2.2 Participants

Dyads of adults with a "high-risk score" and their children were asked to participate in the PA assessment by wearing accelerometers, which collected step count measurements for 5 consecutive days. In Belgium, only one parent per child was evaluated. This was performed by considering the parent with the highest FINDRISC-score. If there was a family with 2 high-risk parents and 2 children, 1 high-risk parent was allocated to each child.

Inclusion criteria for participants were set, this meant that both children and parents had to have data regarding the number of steps and the days of use of the device.

Parents and children who did not wear the device during the requested 5 days and those that reported having T2DM or having had gestational diabetes were excluded from the analyses.

2.3 Measures

Physical activity: PA was assessed using ActiGraph GT1M, GT3X, and GT3X+ accelerometers, which have been demonstrated to have a valid step count function in adults [19] and young people [20]. In both the adults and the children, the monitor was positioned over the left hip and maintained in position with an elasticized belt. These devices do not have an external display, so the user is blinded to the information that the device is gathering.

Researchers from the Feel4Diabetes-study went to the participating schools between April and June 2016 (spring months) during regular school days to give both the adults' and children's devices to the participating children. The children were instructed on how to wear them, as well as receiving written instructions for their use. Children were told to wear the device for 7 whole days starting on the fitting day and to bring them back to school after this period. The researchers made sure that the weekend was included in the measurement days.

Participants were told to use the device during all waking hours, except for water-based activities, like showering, bathing, or swimming. If they engaged in activities in which it was unsafe to wear the device (e.g. martial arts or football), they were told that they could remove it. Children were also given another accelerometer for their parent(s), as well as 1 diary per device in order to write complementary information regarding PA. The parent of each participating child involved was asked to record his or her own diary, as well as his or her child's information regarding the accelerometer or pedometer use, nevertheless, this information has not been included in these analyses.

Data recorded during the first (1^{st}) and last (7^{th}) days were omitted from the analysis, so PA was monitored during 5 consecutive complete days. Cutoffs of >1000 steps and < 30000 steps were determined to consider cases as valid or not [21]. Step count means were calculated for 3 periods: (I) Average days: average step counts for 5 days including 3 weekdays and 2 weekend days ((weekday1 + weekday2 + weekday3 + weekend day1 + weekend day2)/5) (II) Weekdays: average step counts for 3 weekdays ((weekday1 + weekday2 + weekday3)/3), (III) Weekend: average step counts for Saturdays and Sundays ((weekend day1 + weekend day2)/2).

Step count recommendations: To study compliance with step count recommendations, results from the study of Tudor-Locke et al. were used. Regarding sex-specific considerations, the authors suggested that the recommendation would be 13000 to 15000 steps per day in male primary/elementary school children and 11000 to 12000 steps per day in female primary/elementary school children [22]. For adults, a minimum of 10000 steps per day was considered to fulfill current recommendations for both males and females [23].

Body Mass Index and (BMI) Body Mass Index Z-score (BAz): Parental weight and height were measured during the first intervention session in the healthcare center, and children's weight and height were measured in their school during the researchers' visit. Parents' and children's height and weight were measured by a calibrated stadiometer (Seca 813 and 877, Hamburg, Germany) and a portable digital scale (Seca 213, 214, 217, and 225, Hamburg, Germany) in duplicate by trained research staff. BMI was calculated using the formula weight [kg]/height^2 [m], and children's BAz were determined according to the World Health Organization growth standards [24].

Demographic variables: Children's age (6-10 years) and sex (boy or girl), and parental age (<45, 45-54, 55-64, and >65 years) and sex (father or mother) were tested as potential confounders. Educational level in years was classified in 2 categories (less than 13 years and 13 or more years) according to the highest level of education obtained by one of the parents, which may or may not be the parent included in this study. By doing this, we obtained the highest level of education obtained by 1 member of the family. Parental BMI and education were included in the adjusted linear regression analyses after confirming that there were significant differences across categories of BMI in the mean of step counts of all days from adults and in the education categories in the mean of step counts of weekend days in both children and parents **(File 3).**

2.3 Data analysis

Descriptive analyses were carried out with the statistical package IBM SPSS Statistics for Windows, version 26 (SPSS Inc., Chicago, IL. USA). Firstly, children's (n=441) and parents' (n=441) data were assessed for validity separately, this meant having 5 days of data with the minimum number of steps per day required (1000 steps) and not exceeding the maximum number of steps established (30000 steps). After this process, a total of 250 parent-child dyads with complete data were selected.

Descriptive statistics were computed for children and their parents, and differences between sex and parent-child dyads were examined. Continuous data were analyzed with t-tests or ANOVA (in case of normally distributed data) or Mann-Whitney U or Kruskal-Wallis tests (in case of abnormally distributed data), and categorical data were analyzed with X^2 tests **(Table 1 and Table 2)**.

Crosstabs were conducted to compare the percentage of parent-child dyads that complied with the step count recommendations **(Table 3)**. Bivariate Spearman correlation analysis and unadjusted linear regressions between children's steps per day and parents' steps per day were examined, and results are presented in the supplementary section (File 1 and File 2). Separate adjusted linear regressions were performed to analyze the predictor capacity of parental steps per day on children's steps per day, considering all parents with all children and specific dyads, and including parental BMI, and education as covariates **(Table 4)**. All statistical analyses were performed using IBM SPSS version 26, and statistical significance was set at 0.05.

3. Results

In total, 250 dyads of children and their parents from Belgium were included in the study. Sociodemographic characteristics of the sample are shown in **Table 1.** In adults, fathers were older (p=0.002) and presented significantly higher BMI than mothers (p=0.037).

In **Table 2,** average step counts and frequencies of compliance of age-specific recommendations of adults and children are presented. In the adults' group, no significant differences in the total number of steps in the 3 categories (i.e. weekdays, weekend days, and all days), were found (p>0.05). In the children's group, boys reached significantly more steps per day than girls on weekdays (12098.1±2988.8 steps vs. 10501.6±2542.4; p=0.000), on weekend days (9929.1±3968.6 vs. 8784.9±3226.4, p=0.032), and when considering all days together (11230.52±2719.1 vs. 9814.9±2268.4).

Frequencies and percentages of participants complying with recommendations of steps per day are presented in **Table 2**. During weekdays, 26.8% of adults complied with the step count recommendations (i.e. 10000 steps per day), while only 18.4% of adults complied with the recommendations on weekend days. Children presented higher compliance with step count guidelines compared to adults on weekdays (39.6% vs. 26.8%), weekend days (22.4% vs. 18.4%), and all days (26.4% vs. 23.2%). No significant differences were observed between mothers and fathers and girls and boys in terms of steps per day compliance. Dyads of parent-child complying with step count recommendations are presented in **Table 3.** The percentage of compliance in all dyads considering all days was low (11.2%), but especially during the weekend (8.4%).

Since the variables of steps per day were not normally distributed, Spearman correlations were performed to analyze the association between children's steps per day and parents' steps per day. Correlation coefficients in the supplementary section **File 1** show that there are significant positive low correlations between mothers and girls in steps per day on weekend days (r=0.39; p<0.01) and on all days (r=0.34; p<0.01). Significant positive correlations were also found in the father-girl dyad on weekend days (r=0.50, p=0.01) and in the father-boy dyad on all days (r=0.43, p=0.02). When analyzing all dyads, correlations were significant on weekdays, weekend days, and the average of all days (r=0.18, r=0.30 and r=0.27 respectively; $p \leq 0.01$ in all cases).

Coefficients of univariate unadjusted linear regression analyses, performed to analyze the predictor capacity of parental steps per day on children's steps per day, are presented in the supplementary section **File 2.** As expected, all unstandardized beta coefficients were positive and significant when analyzing whether parental steps per day were associated with children's steps on weekdays (β=0.206, p=0.001), on weekend days (β=0.346, p=0.000), and when considering all days (β=0.259, p=0.000). In relation to specific dyads, significant associations were observed in the mother-girl dyads for weekdays (β=0.186, p=0.031), weekend days (β =0.419, p=0.000), and all days (β=0.295, p=0.000). Significant associations were also observed in the father-boy dyads on weekdays and when considering all days (β=0.396, p=0.011 and β=0.448, p=0.017, respectively).

Table 4 displays results from the separate adjusted linear regression analyses for models assessing associations between parents' and children's step counts adjusted by parental BMI and education during weekdays and weekend days and when considering all days together. Significant associations were observed between parents and their children on weekdays (β=0.205; [0.077;0.334], p=0.002), on weekend days (β=0.316; [0.168; 0.464], p=0.000), and when considering all days (β=0.245; [0.110; 0.464], p=0.000). These results can be interpreted as follows: for every 1000 increase in total steps per day that parents walk, children walk on average 244 more steps. Regarding specific parent-child dyads, in the mother-daughter dyad, significant associations were found on weekend days (β=0.418; [0.223; 0.613], p=0.000) and on all days (β=0.294; [0.117; 0.471], p=0.001). In the father-son dyad, significant associations were observed on weekdays (β=0.422; [0.104; 0.740], p=0.012) and when considering all days (β=0.467; [0.082; 0.852], p=0.020). Unadjusted linear regressions are presented in File 3 and when comparing results with the adjusted models, we can confirm that the adjustments for potential confounders did not alter these results.

Discussion

The present study identified associations between the step counts of parents at high risk of developing T2DM with the step counts of their 6- to 10-year-old children. T2DM risk is a shared risk between adults and their children because families share their genetic backgrounds and lifestyle habits. PA plays an important role in the prevention of T2DM; therefore, it is important to investigate the PA levels of adults at risk of developing T2DM and their children. To the authors' knowledge, this is the first study to examine associations between the step counts of adults at risk of developing T2DM and their children's step counts.

On average, children accumulated approximately 11237 steps per day, which is similar to results from a previous study [25], in which mean step counts of 9- to 10-year-old children ranged from 9746 to 11251 steps per day depending on the type of transport they used to go to school. Across all ages, boys accumulated more steps than girls, this has previously been found in studies conducted in children from Greece [26] and in from the USA[27].

Regarding parents, mean step counts in all days (8106 steps per day) was similar to the mean of step counts found in a representative sample of Japanese 30 – 49 year-old adults, that ranged between 7800 and 8127 per day [28].

The main findings of this study show that there is a positive association between parents' and children's step counts, especially between mothers and daughters during all days (including weekdays and weekend days) and between mothers and sons during weekend days. This is comparable with a previous study [29] in a healthy sample of parents and children from the Czech Republic also showing that correlations of steps per day during weekdays in children and their parents were positive but low, and more specifically significant between mothers and daughters, mothers and sons, and fathers and sons. Another study [30], aiming to assess parent-adolescent patterns of PA, sedentary behaviors, and sleep among overweight and obese adolescents showed that parent-adolescent moderate to vigorous PA was significantly associated on weekdays and weekend days, nonetheless, total step count associations appeared to be non significant. This confirms that at older ages and considering different conditions, such as overweight or obesity associations may vary over time. This also confirms the fact that it is important to target both parental PA and children's PA in healthy populations as well as populations with a higher risk for the development of chronic diseases so that preventive interventions can be implemented for adults at risk and children that may be at risk in the future.

Results indicated that during the weekend, the association of step counts between children and their parents was higher than during weekdays (β=316, p=0.000 vs. β=0.205, p=0.001). These results are comparable of those in another study, where associations between parents´ and 8-year-old children´s step counts were evaluated through adjusted regression models, the effect was significant in the parent-boy and the parent-girls dyads, both in weekdays and weekends days but coefficients were relatively small, eventhough the study sample was representative from the study´s population [13].

This may be explained by the fact that during the weekend days children are more likely to be with their parents; that is also the case after school and during the evening [13]. Whereas weekday routines are consistent and similar for children (school) and parents (work, housework) most of the time.

Consequently, future research should analyze the effect of interventions aiming to prevent the development of T2DM in adults at risk and their children considering that steps per day in children start to decline with age [31]. We consider that our main findings are the low compliance of steps per day of both parents and their children and, even though weak positive associations between step counts of mothers at risk and their daughters and fathers at risk and their sons were found, this could indicate the beginning of parental PA levels as an external factor of influence on children's PA level. We must acknowledge that in this study, the differences in sample sizes of specific dyads may have an influence on the results found, given that the mother-daughter dyad was the most prevalent. However, given that significant associations were also found in the father-son dyad, we can conclude that gender parent-child resemblance may explain these differences. This confirms the need for early prevention interventions among adults at risk of developing T2DM in the future and their children, especially among vulnerable populations such as this in Europe such vulnerable populations in Europe. Knowing that associations between parental step counts and their children's step counts exist, for future research, it would be interesting to address not only the changes in children's PA levels after a lifestyle intervention but also the changes in the parent-child associations. Also, the determinants of these associations could be addressed so that interventions can be more personalized and efficient in each country.

Despite the fact that this study found higher associations between mothers and their children, a previous study about a PA program that aimed to increase PA behavior in preadolescent girls showed that they would benefit from a meaningful engagement of fathers [32], which confirms that fathers also play a key role in the improvement of PA levels. Given that there is evidence showing that there are associations between children's and parents' co-TV viewing and total screen time [33] and inactivity [34], for future studies, we think it would be relevant not only to assess objective PA levels but also to measure 24-hour movement behaviors considering current recommendations[35] so that sedentary behaviors and sleep can also be addressed to establish associations between children and their parents.

The current study has some limitations. First, the aim of the Feel4Diabetes-study was to develop an evidence-based intervention for adults at high risk of developing T2DM, which means that we only have objective PA data for families at higher risk of T2DM. This means that it is not possible to compare these associations with families at low risk of developing T2DM or to compare these associations with families that have T2DM. Secondly, cross-sectional analyses of the data indicate that causal associations cannot be assumed. Future studies aiming to decrease the risk of developing T2DM should assess changes in physical activity levels in both children and their parents longitudinally. On the other hand, even though participants of this study did not report any important movement limitation, in this study, no evaluation before the assessment with accelerometers was performed in children or their parents. This is something that should be addressed in order to adjust the data by confounding factors like movement limitations or illnesses associated with the performance of daily activities.

This study also has some strengths. Firstly, objectively assessed PA data for children and their parents were obtained, this provides high-quality information about PA. Another strength is that highly trained staff, including sports scientists, dietitians, nurses, and medical doctors, performed all measurements. Finally, a further strength of this study is that associations have been addressed in 4 types of adult-child dyads, which is important because we could observe differences between mothers and fathers with their children and establish stronger associations between mothers and daughters and fathers and sons.

The results of this study indicate that most adults at risk of developing diabetes do not comply with current recommendations of steps per day and neither do their children, who may be affected not only by the genetic risk of diabetes but also by the inherited habit of not being physically active. On the other hand, results showed that there are parent-child associations of steps per day on weekdays, weekend days, and all days. We should acknowledge that mothers present stronger associations with their daughters and fathers with their sons, but it does not exclude the fact that both parents play an important role in sharing lifestyle habits with their children. The positive associations found between step counts from child-parent dyads from the Feel4Diabetes-study, confirm the need for early prevention interventions among adults at risk of developing T2DM in the future and children from high SES countries like Belgium. A feasible intervention strategy could be targeting co-PA can be to increase PA levels in families at high risk of developing T2DM in the future.

Health providers should always remind patients that there are recommendations of minimum step counts per day, but no upper limit is yet known, so the more the better. Every step counts.

Conflict of interest

The authors declare that there are no conflicts of interest.

Ethical approval

The Feel4Diabetes-study was conducted according to the standards of the Declaration of Helsinki. Also, the institution of each participant center of the study provided ethical approval prior to data collection: Ethical Committee of Ghent University Hospital (Belgium), Committee for the Ethics of the Scientific Studies (KENI) at the Medical University of Varna (Bulgaria), Ethics Committee of THL (Finland), the Ethics Committee of Harokopio University of Athens, the Greek Ministry of Education, Research and Religious Affairs and the Municipalities of Kallithea, Peristeri, Piraeus and Keratsini-Drapetsona (Greece), the Bioethics Committee of University of Debrecen (Hungary), and the Ethical Committee of Clinical Research of Aragon (Spain).

Informed consent

Written consent was obtained from parents for their participation and their children's participation. Children gave verbal assent.

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Feel4Diabetes-study group

Coordinator: Yannis Manios

Steering Committee: Yannis Manios, Greet Cardon, Jaana Lindström, Peter Schwarz, Konstantinos Makrilakis, Lieven Annemans, Winne Ko

Harokopio University (Greece)

Yannis Manios, Kalliopi Karatzi, Odysseas Androutsos, George Moschonis, Spyridon Kanellakis, Christina Mavrogianni, Konstantina Tsoutsoulopoulou, Christina Katsarou, Eva Karaglani, Irini Qira, Efstathios Skoufas, Konstantina Maragkopoulou, Antigone Tsiafitsa, Irini Sotiropoulou, Michalis Tsolakos, Effie Argyri, Mary Nikolaou, Eleni-Anna Vampouli, Christina Filippou, Kyriaki Apergi, Amalia Filippou, Gatsiou Katerina, Efstratios Dimitriadis

Finnish Institute for Health and Welfare (Finland)

Jaana Lindström, Tiina Laatikainen, Katja Wikström, Jemina Kivelä, Päivi Valve, Esko Levälahti, Eeva Virtanen, Tiina Pennanen, Seija Olli, Karoliina Nelimarkka

Ghent University (Belgium)

Department of Movement and Sports Sciences: Greet Cardon, Vicky Van Stappen, Nele Huys

Department of Public Health: Lieven Annemans, Ruben Willems

Department of Endocrinology and Metabolic Diseases: Samyah Shadid

Technische Universität Dresden (Germany)

Peter Schwarz, Patrick Timpel

University of Athens (Greece)

Konstantinos Makrilakis, Stavros Liatis, George Dafoulas, Christina-Paulina Lambrinou, Angeliki Giannopoulou

International Diabetes Federation European Region (Belgium)

Winne Ko, Ernest Karuranga

Universidad De Zaragoza (Spain)

Luis Moreno, Fernando Civeira, Gloria Bueno, Pilar De Miguel-Etayo, Esther Mª Gonzalez-Gil, María L. Miguel-Berges, Natalia Giménez-Legarre; Paloma Flores-Barrantes, Aleli M. Ayala-Marín, Miguel Seral-Cortés, Lucia Baila-Rueda, Ana Cenarro, Estíbaliz Jarauta, Rocío Mateo-Gallego

Medical University of Varna (Bulgaria)

Violeta Iotova, Tsvetalina Tankova, Natalia Usheva, Kaloyan Tsochev, Nevena Chakarova, Sonya Galcheva, Rumyana Dimova, Yana Bocheva, Zhaneta Radkova, Vanya Marinova, Yuliya Bazdarska, Tanya Stefanova

University of Debrecen (Hungary)

Imre Rurik, Timea Ungvari, Zoltán Jancsó, Anna Nánási, László Kolozsvári, Csilla Semánova, Éva Bíró, Emese Antal, Sándorné Radó

Extensive Life Oy (Finland)

Remberto Martinez, Marcos Tong

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4. References

1. Zimmet PZ, Alberti KG. Epidemiology of Diabetes-Status of a Pandemic and Issues Around Metabolic Surgery. *Diabetes Care.* 2016;39(6):878-883.
2. Drong AW, Lindgren CM, McCarthy MI. The genetic and epigenetic basis of type 2 diabetes and obesity. *Clin Pharmacol Ther.* 2012;92(6):707-715.
3. Hu Z, Gao F, Qin L, Yang Y, Xu H. A Case-Control Study on Risk Factors and Their Interactions with Prediabetes among the Elderly in Rural Communities of Yiyang City, Hunan Province. *J Diabetes Res.* 2019;2019:1386048.
4. Kolb H, Martin S. Environmental/lifestyle factors in the pathogenesis and prevention of type 2 diabetes. *BMC medicine.* 2017;15(1).
5. Lascar N, Brown J, Pattison H, Barnett A, Bailey C, Bellary S. Type 2 Diabetes in Adolescents and Young Adults. *The lancet Diabetes & endocrinology.* 2018;6(1).
6. American Diabetes Association. Standards of medical care in diabetes--2015: summary of revisions. *Diabetes Care.* 2015;38 Suppl:S4.
7. Knowler WC, Barrett-Connor E, Fowler SE, et al. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. *N Engl J Med.* 2002;346(6):393-403.
8. American Diabetes Association. 3. Prevention or Delay of Type 2 Diabetes: Standards of Medical Care in Diabetes-2019. In. *Diabetes Care.* Vol 42. 2018/12/19 ed2019:S29-s33.
9. Fukuoka Y, Gay CL, Joiner KL, Vittinghoff E. A Novel Diabetes Prevention Intervention Using a Mobile App: A Randomized Controlled Trial With Overweight Adults at Risk. *Am J Prev Med.* 2015;49(2):223-237.
10. Ball GDC, Ambler KA, Keaschuk RA, et al. Parents as Agents of Change (PAC) in pediatric weight management: The protocol for the PAC randomized clinical trial. *BMC Pediatr.* 2012;12:114.
11. Davison KK, Birch LL. Obesigenic families: parents' physical activity and dietary intake patterns predict girls' risk of overweight. *Int J Obes Relat Metab Disord.* 2002;26(9):1186-1193.
12. Larsen H, Dinkel D, Warehime S, Berg K. The Relationship Between Parental and Child Physical Activity in a Rural Community. *Fam Community Health.* 2017;40(4):331-337.
13. Garriguet D, Colley R, Bushnik T. Parent-Child association in physical activity and sedentary behaviour. *Health Rep.* 2017;28(6):3-11.
14. Brouwer SI, Kupers LK, Kors L, et al. Parental physical activity is associated with objectively measured physical activity in young children in a sex-specific manner: the GECKO Drenthe cohort. *BMC Public Health.* 2018;18(1):1033.
15. Bringolf-Isler B, Schindler C, Kayser B, Suggs LS, Probst-Hensch N. Objectively measured physical activity in population-representative parent-child pairs: parental modelling matters and is context-specific. *BMC Public Health.* 2018;18(1):1024.
16. Djafarian K, Speakman JR, Stewart J, D MJ. Familial resemblance of body composition, physical activity, and resting metabolic rate in pre-school children. *Rep Biochem Mol Biol.* 2013;2(1):1-15.
17. Manios Y, Androutsos O, Lambrinou CP, et al. A school- and community-based intervention to promote healthy lifestyle and prevent type 2 diabetes in vulnerable families across Europe: design and implementation of the Feel4Diabetes-study. *Public Health Nutr.* 2018;21(17):3281-3290.
18. Lindstrom J, Tuomilehto J. The diabetes risk score: a practical tool to predict type 2 diabetes risk. *Diabetes Care.* 2003;26(3):725-731.
19. Sasaki JE, John D, Freedson PS. Validation and comparison of ActiGraph activity monitors. *J Sci Med Sport.* 2011;14(5):411-416.
20. De Craemer M, De Decker E, Santos-Lozano A, et al. Validity of the Omron pedometer and the actigraph step count function in preschoolers. *J Sci Med Sport.* 2015;18(3):289-293.

21. David A. Rowe MTM, Thomas D. Raedeke and Joanna Lore. Measuring physical activity in children with pedometers: Reliability, reactivity, and replacing missing data. *Pediatric Exercise Science.* 2006;16:343-354.
22. Tudor-Locke C, Craig CL, Beets MW, et al. How many steps/day are enough? for children and adolescents. *Int J Behav Nutr Phys Act.* 2011;8:78.
23. Tudor-Locke C, Bassett DR, Jr. How many steps/day are enough? Preliminary pedometer indices for public health. *Sports Med.* 2004;34(1):1-8.
24. *WHO Child Growth Standards: Methods and development: weight-forheight and bodymass index-for-age.* [computer program]. 2006.
25. Owen C, Nightingale C, Rudnicka A, et al. Travel to School and Physical Activity Levels in 9-10 Year-Old UK Children of Different Ethnic Origin; Child Heart and Health Study in England (CHASE). *PloS one.* 2012;7(2).
26. Michalopoulou M, Gourgoulis V, Kourtessis T, Kambas A, Dimitrou M, Gretziou H. Step Counts and Body Mass Index Among 9-14 Years Old Greek Schoolchildren. *Journal of sports science & medicine.* 2011;10(1).
27. Trost. SG, Pate. RR, Sallis. JF, et al. Age and gender differences in objectively measured physical activity in youth. *Medicine and science in sports and exercise.* 2002;34(2).
28. Tanaka S. Status of physical activity in Japanese adults and children. *Annals of human biology.* 2019;46(4).
29. Sigmundova D, Sigmund E, Vokacova J, Kopkova J. Parent-child associations in pedometer-determined physical activity and sedentary behaviour on weekdays and weekends in random samples of families in the Czech Republic. *Int J Environ Res Public Health.* 2014;11(7):7163-7181.
30. Tu AW, Watts AW, Masse LC. Parent-Adolescent Patterns of Physical Activity, Sedentary Behaviors and Sleep Among a Sample of Overweight and Obese Adolescents. *J Phys Act Health.* 2015;12(11):1469-1476.
31. Tudor-Locke C, Johnson WD, Katzmarzyk PT. Accelerometer-determined steps per day in US children and youth. *Med Sci Sports Exerc.* 2010;42(12):2244-2250.
32. Morgan PJ, Young MD, Barnes AT, Eather N, Pollock ER, Lubans DR. Engaging Fathers to Increase Physical Activity in Girls: The "Dads And Daughters Exercising and Empowered" (DADEE) Randomized Controlled Trial. *Ann Behav Med.* 2019;53(1):39-52.
33. Latomme J, Van Stappen V, Cardon G, et al. The Association between Children's and Parents' Co-TV Viewing and Their Total Screen Time in Six European Countries: Cross-Sectional Data from the Feel4diabetes-Study. *Int J Environ Res Public Health.* 2018;15(11).
34. Fogelholm M, Nuutinen O, Pasanen M, Myohanen E, Saatela T. Parent-child relationship of physical activity patterns and obesity. *Int J Obes Relat Metab Disord.* 1999;23(12):1262-1268.
35. Tremblay M, Carson V, Chaput J, et al. Canadian 24-Hour Movement Guidelines for Children and Youth: An Integration of Physical Activity, Sedentary Behaviour, and Sleep. *Applied physiology, nutrition, and metabolism = Physiologie appliquee, nutrition et metabolisme.* 2016;41(6 Suppl 3).

1. Tables

Table 1. Participant characteristics

	Adults				Children			
	Total	Mothers	Fathers	*p*	Total	Girls	Boys	*p*
% (n)	100 (250)	77.6 (194)	22.4 (56)	-	100 (250)	54.4 (136)	45.6 (114)	-
Age, y	39.4±5.2(236)	38.7±4.4(181)	41.8±6.7(55)	**0.002**	8.0±0.9(241)	8.0±0.9 (131)	8.0±0.9 (110)	0.884
BMI (Kg/m^2)	27.7±5.2(216)	27.4±5.5(164)	28.5±4.0(52)	**0.037**	16.9±2.45(241)	17.2±2.6 (131)	16.6±2.3 (110)	0.090
BMI Z-Score	-	-	-	-	0.47±1.1(241)	0.54±1.1 (131)	0.37±1.1 (110)	0.105
Normal	36.8 (81)	40.4 (68)	25.0 (13)		70.1 (169)	65.2 (85)	76.4 (84)	
Overweight	32.3 (71)	29.8 (50)	40.4 (21)	0.118	20.7 (50)	25.0 (33)	15.5 (17)	0.142
Obesity	30.9 (68)	29.8 (50)	34.6 (18)		9.1 (22)	9.8 (13)	8.2 (9)	
Education %,n								
Low	13.0 (31)	13.0 (24)	13.0 (7)	0.998	-	-	-	-
High	87.0 (208)	87.0 (161)	87.0 (47)		-	-	-	
Parent -child dyads % (n)								
Daughters		43.6 (109)	10.8 (27)					
Sons		34.0 (85)	11.6 (29)					

Means and standard deviations are presented for continuous variables, percentages and frequencies are presented for categorical variables. For adults, categories of BMI and for children, categories of sex-specific BAZ are presented, both according to the World Health Organization references. p-values in bold represent differences between mothers and fathers and between girls and boys.

Table 2. Mean ± SD of steps/day and compliance % (n) with current step count recommendations of step counts per day for children and their parents

	Adults				Children			
	Total	Mothers	Fathers	*p*	Total (250)	Girls (136)	Boys (114)	*p*
[a]Weekdays	8585.8±2993.0(250)	8587.78±2898.4(194)	8578.9±3328.3(56)	0.955	11237.4±2852.3(250)	10501.6±2542.4(136)	12098.1±2988.8(114)	**0.000**
[b]Yes	26.8 (67)	20.0 (50)	6.8 (17)	0.495	39.6 (99)	40.4 (55)	38.6 (44)	0.766
[b]No	73.2 (183)	57.6 (144)	15.6 (39)		60.4 (151)	59.6 (81)	61.4 (70)	
[a]Weekend	7387.5±3287.9(250)	7283.7±3217.4(194)	7746.9±3527.9(56)	0.339	11229.6±2862.4(250)	8784.9±3226.4(136)	9929.1±3968.6(114)	**0.032**
[b]Yes	18.4 (46)	12.4 (31)	6.0 (15)	0.066	22.4 (56)	22.1 (30)	22.8 (26)	0.888
[b]No	81.6 (204)	65.2 (163)	16.4 (41)		77.6 (194)	77.9 (106)	77.2 (88)	
[a]All days	8106.5±2593.5(250)	8066.16±2541.9(194)	8246.1±2784.3(56)	0.510	10460.4±2577.6	9814.9±2268.4 (136)	11230.52±2719.1(114)	**0.000**
[b]Yes	23.2 (58)	6.8 (17)	16.4 (41)	0.150	26.4 (66)	27.2 (37)	25.4 (29)	0.752
[b]No	76.8 (192)	15.6 (39)	61.2 (153)		73.6 (184)	39.6 (99)	74.6 (85)	

Means and standard deviations are presented for continuous variables, frequencies and percentages are presented for categorical variables. [a] = Number of steps per day, [b]= Compliance of recommendations of steps per day. Recommendations of steps per day of Tudor-Locke et al. 2004 and 2011 were used for adults and children, respectively (≥10000 steps/day for adults, ≥13000 steps/day for boys and ≥11000 steps/day for girls) p-values in bold represent differences between mothers and fathers and between girls and boys. Abbreviations: SD: standard deviation.

Table 3. Crosstabs of compliance with steps/day recommendations between children and their parents

	Girls	Boys	Children
		n (%)	
Weekdays			
Mothers	16 (14.7)	9 (10.6)	
Fathers	3 (11.1)	4 (13.8)	
Parents			32 (12.8)
Weekend days			
Mothers	8 (7.3)	9 (10.6)	
Fathers	2 (7.4)	4 (13.8)	
Parents			21 (8.4)
All days			
Mothers	11 (10.1)	6 (7.1)	
Fathers	0 (0)	3 (10.3)	
Parents			28 (11.2)

Frequencies and percentages of parent-child dyads that comply with recommendations. Recommendations of steps per day of Tudor-Locke et al. 2004 were used for adults (>10000 steps/day) and Tudor-Locke et al. 2011 for children (>13000 steps/day in boys and >11000 steps/day in girls). No significant associations were observed in compliance between dyads (p>0.05 in all cases).

Table 4. Associations between parental and children´s number of steps per day. Results from adjusted multiple linear regression models

	Unstd. β	Std. β	*95% CI*	*p* value
Parental steps/day in weekdays	0.205	0.213	[0.077; 0.334]	**0.002**
Parental steps/day in weekend days	0.316	0.284	[0.168; 0.464]	**0.000**
Parental steps/day in all days	0.245	0.244	[0.110; 0.380]	**0.000**
Maternal steps/day in weekdays in girls	0.169	0.186	[-0.018; 0.357]	0.076
Maternal steps/day in weekend days in girls	0.418	0.427	[0.223; 0.613]	**0.000**
Maternal steps/day in all days in girls	0.294	0.339	[0.117; 0.471]	**0.001**
Paternal steps/day in weekdays in girls	0.190	0.252	[-0.152; 0.533]	0.261
Paternal steps/day in weekend days in girls	0.283	0.371	[-0.074; 0.604]	0.114
Paternal steps/day in all days in girls	0.195	0.247	[-0.181; 0.571]	0.293
Maternal steps/day in weekdays in boys	0.209	0.197	[-0.052; 0.469]	0.115
Maternal steps/day in weekend days in boys	0.144	0.096	[-0.215; 0.502]	0.427
Maternal steps/day in all days in boys	0.147	0.123	[-0.150; 0.443]	0.328
Paternal steps/day in weekdays in boys	0.422	0.518	[0.104; 0.740]	**0.012**
Paternal steps/day in weekend days in boys	0.360	0.318	[-0.084; 0.804]	0.107
Paternal steps/day in all days in boys	0.467	0.471	[0.082; 0.852]	**0.020**

Results from separate multiple linear regression models. Unstd, unstandardized; Std, standardized; CI, confidence interval. β coefficient, confidence intervals at 95% and *p*-values are presented. All models are adjusted by parental BMI and maximum familiar educational level Sample size: 215, Dyad of mothers and girls =94, Dyad of fathers and girls =25, Dyad of mother and boys = 70 and dyad of fathers and boys =26.

File 1. Bivariate Spearman correlations between parental and children's steps/day

	Girls	Boys	All
	Correlation coefficient (p value)		
Weekdays			
Mothers	0.18 (0.06)	0.13 (0.22)	
Fathers	0.17 (0.40)	0.36 **(0.05)**	
Parents			0.18 **(0.01)**
Weekend days			
Mothers	0.39 **(0.00)**	0.19 (0.09)	
Fathers	0.50 **(0.01)**	0.37 **(0.05)**	
Parents			0.30 **(0.00)**
All days			
Mothers	0.34 **(0.00)**	0.21 (0.06)	
Fathers	0.28 (0.15)	0.43 **(0.02)**	
Parents			0.27 **(0.00)**

p-values in bold represent significant values.

File 2. Associations between parental and children´s number of steps per day. Results from unadjusted multiple linear regression models

	Unstd. β	Std. β	*95% CI*	*p* value
Parental steps/day in weekdays	0.206	0.215	[0.089; 0.323]	**0.001**
Parental steps/day in weekend days	0.346	0.314	[0.215; 0.477]	**0.000**
Parental steps/day in all days	0.259	0.261	[0.139; 0.379]	**0.000**
Maternal steps/day in weekdays in girls	0.186	0.207	[0.018; 0.355]	**0.031**
Maternal steps/day in weekend days in girls	0.419	0.440	[0.255;0.583]	**0.000**
Maternal steps/day in all days in girls	0.295	0.347	[0.142; 0.447]	**0.000**
Paternal steps/day in weekdays in girls	0.161	0.216	[-0.139; 0.461]	0.280
Paternal steps/day in weekend days in girls	0.287	0.368	[-0.012; 0.585]	0.059
Paternal steps/day in all days in girls	0.190	0.243	[-0.122; 0.502]	0.221
Maternal steps/day in weekdays in boys	0.198	0.194	[-0.020; 0.417]	0.075
Maternal steps/day in weekend days in boys	0.245	0.176	[-0.054; 0.543]	0.543
Maternal steps/day in all days in boys	0.203	0.180	[-0.040; 0.447]	0.100
Paternal steps/day in weekdays in boys	0.396	0.466	[0.099; 0.693]	**0.011**
Paternal steps/day in weekend days in boys	0.396	0.351	[-0.021; 0.813]	0.062
Paternal steps/day in all days in boys	0.448	0.441	[0.088; 0.808]	**0.017**

Linear regressions were performed separately. β coefficient, confidence intervals at 95% and *p*-values are presented. Total sample = 250 children and parents. Dyad of mothers and girls =109, Dyad of fathers and girls =27, Dyad of mother and boys = 85 and dyad of fathers and boys = 29.

File 3. Differences in steps per day in adults and children according to potential confounders

Step counts in adults, Mean ± SD (n)				Step counts in children, mean ± SD (n)			
	Weekdays	**Weekend days**	**All days**		**Weekdays**	**Weekend days**	**All days**
Education				**Education**			
Low	8384.0±2967.6(31)	6038.38±2356.2(31)	7445.74±2155.5(31)	Low	11755.7±3147.5(31)	8043.76±2179.4(31)	10270.9±2253.6(31)
High	8665.89±3039.9(208)	7762.51±3313.9(208)	8304.47±2639.1(208)	High	11130.4±2843.0(208)	9561.31±3787.3(208)	10502.8±2639.3(208)
	0.865	***0.004***	*0.145*		*0.261*	***0.025***	*0.643*
BMI				**BAZ**			
Normal	9051.8±3236.6(81)	8130.9±3895.1(81)	8683.4±3004.6(81)	Normal	11227.9±2942.4(169)	9437.4±3807.4(169)	10511.7±10511.7(169)
Overweight	8813.7±3000.2(71)	7605.4±2871.1(71)	8330.4±2424.7(71)	Overweight	11207.1±2696.6(50)	9337.15±3190.1(50)	10459.1±2294.0(50)
Obesity	8100.7±2844.1(68)	6730.9±2502.8(68)	7552.8±2094.6(68)	Obesity	10990.3±2861.9(22)	8735.41±3358.1(22)	10088.4±2223.7(22)
	0.176	*0.071*	***0.041***		*0.936*	*0.555*	*0.771*
Age				**Age**			
<45	8683.7±2960.1(201)	7567.4±3381.9(201)	8237.2±2574.1(201)	6y	10787.0±2859.9(40)	9765.51±(40)	10378.4±2505.1(40)
≥45	8187.9±3107.5(47)	6451.5±2655.7(47)	7493.4±2635.0(47)	7y	11119.4±2297.8(83)	9018.89±(83)	10279.2±2238.3(83)
	0.167	0.054	0.066	8y	11651.2±3320.6(79)	9767.06±(79)	10897.5±3039.5(79)
				9y	10986.2±2864.35(33)	8841.14±(22)	10128.2±2158.8(22)
				10y	11187.2±11187,22(3)	8548.83±(3)	10131.9±4533.1(3)
					0.563	*0.574*	*0.515*

BMI, Body Mass Indez, Baz, Body Mass Index for Age z Score. p-values in bold represent significant differences across categories. U-Mann-Whitney and Kruskal-Wallis analyses were performed in non-normally distributed data (mean of step counts in weekdays, weekend days and all days for adults and step counts during weekend days for children) and T-test and ANOVA analyses were performed in normally distributed data (step count in weekdays and considering all days for children).