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Original Article

Temporal trends of physical activity and sedentary behavior among Greek school-age children: A comparison of two cross-sectional cohorts

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Abstract:
Many studies have highlighted the importance of physical activity in fostering health and preventing diseases among children and adolescents. Concurrently, mounting evidence underscores the detrimental health effects associated with high levels of sedentary behavior in children. Understanding the temporal changes in children's physical activity and sedentary behavior patterns is crucial for identifying evolving contexts that may require tailored interventions. This study investigates gender-specific changes in accelerometer-measured physical activity and sedentary behavior patterns among 8–11-year-old children from the same region of Greece, juxtaposing data from two different time frames (2014 and 2021). The cohort comprised 144 school-age children, with 68 participants from the 2014 cohort and 76 from the 2021 cohort. Physical activity and sedentary time were tracked using hip-worn accelerometers (Actigraph GT3X+). Participants were directed to wear the device continuously for seven consecutive days during their waking hours. Vector magnitude counts per minute and daily step counts were used to assess the total volume of physical activity, and Freedson population-specific cut-points for children were applied to classify physical activity levels. Factorial ANOVA models were conducted independently for each physical activity metric to explore discrepancies between the two measurement periods for each gender. The study's findings revealed a temporal trend indicating a decline in light physical activity alongside a significant increase in the percentage of total daily sedentary behavior. However, steps per day, counts per minute, and levels of moderate-to-vigorous physical activity remained relatively stable and did not significantly change. The average duration of sedentary bouts significantly increased only among girls. The results also indicated a slight increase from 2014 to 2021 regarding the proportion of children meeting physical activity recommendations. Modern children allocate less time to light physical activity and more time to sedentary pursuits, significantly increasing uninterrupted sedentary periods during the day. Our results underscore the need for tailored initiatives to promote and enable physical activity, particularly among girls. Addressing barriers and fostering inclusive opportunities is imperative to empower all children to adopt active and healthy lifestyles.
Keywords: changes over time, physical activity intensities, accelerometer, sedentary bouts, childhood

Introduction

The role of physical activity (PA) in health promotion and disease prevention in children and youth has been the focus of numerous studies (Poitras, Gray, Borghese, Carson, Chaput, Janssen, et al., 2016). It is well documented that moderate-to-vigorous physical activity (MVPA) is associated with many positive physical health outcomes, such as maintaining a healthy weight (Gualdi-Russo, Rinaldo, Toselli & Zaccagni, 2021), developing strong bones (Bland, Heatherington-Rauth, Howe, Going & Bea, 2020; Michalopoulou, Kambas, Leontsini, Chatzinikolaou, Draganidis, Avloniti, et al., 2013), and enhancing cardiometabolic health (Stuart, 2017; Ekelund, Luan, Sherar, Esliger, Griew & Cooper, 2012). There are also identified favorable relationships between PA and a wide range of indicators encompassing psychological, social, and cognitive health in children and youth (Poitras et al., 2016). At the same time, there is emerging evidence of the negative health effects of high levels of sedentary behavior (SB) in children (Carson, Hunter, Kuzik, Gray, Poitras, Chaput, et al., 2016), including body composition (Ferrari, Kovalskys, Fisberg, Gómez, Rigotti, Sanabria, et al., 2020), cardiometabolic function (Väistö, Haapala, Viitasalo, Schnurr, Kilpeläinen, Karjalainen, et al., 2019) and bone health (Koedijk, van Rijswijk, Oranje, van den Bergh, Bours, Savelberg, et al., 2017), with an associated public health burden. The unfavorable consequences of SB may not only be determined by the total volume, but also by its accumulation pattern, with prolonged bouts of SB suggested as particularly detrimental (Dalene, Kolle, Steene-Johannessen, Hansen, Ekelund, Grydeland, et al., 2022).

The World Health Organization (WHO) recommends that children and adolescents aged 5 to 17 years should participate in MVPA for an average of 60 min per day and limit the amount of sedentary time (Bull, Al-Ansari, Biddle, Borodulin, Buman, Cardon, et al., 2020). Children nevertheless spend a large proportion of their day in SB and many appear to be physically inactive, i.e., not achieving the recommended MVPA threshold (Cooper, Goodman,

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Page, Sherar, Esliger, van Sluijs, et al., 2015), while sex and age differences in PA have been consistently reported in the literature with boys and younger children being more active (Steene-Johannessen, Hansen, Dalene, Kolle, Northstone, Møller, et al., 2020). Physical inactivity and a sedentary lifestyle in youth are recognized as risk factors for chronic diseases later in life (van Sluijs, Ekelund, Crochemore-Silva, Guthold, Ha, Lubans, et al., 2021; Carson et al., 2016; Kohl, Craig, Lambert, Inoue, Alkandari, Leetongin, et al., 2012). In response, a global priority has been set to decrease the prevalence of physical inactivity by 15% in 2030 (World Health Organization, 2018). Accurate PA assessment and understanding trends in PA and SB over time is an essential first step in this process.

PA is a multi-dimensional concept, and no single measure can assess all its facets (Sylvia, Bernstein, Hubbard, Keating & Anderson, 2014). In addition to total volume, accumulation of PA and SB patterns seems to play a role in children's health outcomes (Downing, Hinkley, Timperio, Salmon, Carver, Cliff, et al., 2021). Various approaches have been employed to evaluate PA in children and adolescents, including questionnaires, activity logs, pedometers and accelerometers. Practicality, validity, and reliability are crucial factors to consider when determining the most suitable methods for assessing PA levels in clinical contexts (Pavlidou, Michalopoulou, Aggelousis & Taxildaris, 2011). Accelerometers have become the method of choice for measuring youth PA in free-living conditions because of their accuracy (Cain, Sallis, Conway, Van Dyck & Calhoon, 2013) and ability to provide detailed information about PA intensity and different PA and SB patterns (Jussila, Husu, Vähä-Ypyä, Tokola, Kokko, Sievänen, et al., 2022). They are also easy to use, durable, and relatively low-cost (Corder, Ekelund, Steele, Wareham & Brage, 2008; Trost, 2007), although processing raw accelerometer data into behavioral PA patterns remains a challenge (Ahmadi, Pfeiffer & Trost, 2020).

The decade spanning from 2010 to 2020 witnessed notable shifts in the PA and health landscape for children and adolescents worldwide. Recreational screen time, a component of children's SB, has experienced a rapid surge over the past decade, posing a threat to the time allocated for engaging in physical activities (Valtonen, Kyhälä & Reunamo, 2021). The rise of accessible and affordable technology, along with digital communication over the past decade, is widely regarded as having fundamentally transformed how children participate in screen-based activities (Dalene et al., 2022). Additionally, advancements in the field of PA and health have led to a deeper comprehension of declines in MVPA and increases SB throughout childhood (Farooq, Martin, Janssen, Wilson, Gibson, Hughes, & Reilly, 2020). Nevertheless, despite these trends, a growing body of evidence emphasizes the advantages of reducing screen time and promoting MVPA among children and adolescents (Carson et al., 2016; Poitras et al., 2016). Furthermore, the COVID-19 pandemic disturbed routines and lifestyle activities, particularly with the closure of schools and transition to online learning, which may have reinforced physical inactivity and sedentariness (Bates, Zieff, Stanford, Moore, Kerr, Hanson, et al., 2020). There is evidence suggesting that accelerometer-measured PA levels decreased and SB remained high in children, even after schools reopened (Ten Velde, Lubrecht, Arayess, van Loo, Hesselink, Reijnders, et al., 2021). Few studies have assessed temporal changes in SB patterns, using activity monitors (Dalene et al., 2022). Identifying changing patterns over time, namely temporal trends, in children's PA and SB is important and can inform policy and other intervention needs toward national and international targets. Such temporal trends appeared relatively stable over the past decade (Reilly, Barnes, Gonzalez, Huang, Manyanga, Tanaka, et al., 2022), but there is a need for more recent evidence, ideally derived from comparable and valid study designs and methods. Therefore, the present study aimed to investigate gender-specific changes in accelerometer-measured PA and SB patterns, between two time points, 2014 and 2021, in 8–11-year-old children from the same region of Greece.

Material & methods

Participants

Participants included 144 children in total, 68 from the 2014 cohort, and 76 from the 2021 cohort, average age 9.1±1.3 years and 9.4±1.2 years respectively. Participants were students in primary schools and had no reported musculoskeletal issues or diagnosed disorders restricting PA or special educational needs. The present study comprises data from two cross-sectional studies assessing PA and SB in children from the prefecture of Rodopi, Northern Greece (Leontsini, 2023; Pavlidou, 2022). The two studies took place in spring 2014 and autumn 2021 respectively and examined the relationships between physical activity and health indices in school-age children. Written parental consent was obtained before children participated in both studies.

Procedure/ Measure Instruments/Anthropometrics

The study has received ethical approval from the Research Ethics Committee of Democritus University of Thrace (DUTH/EHDE/12213/70) and complies with ethical practices. Height was measured barefoot to the nearest 0.1cm using a portable stadiometer (Seca-206). Body weight was measured barefoot with light clothing to the nearest 0.1kg on a digital scale (Charder- MA801). Accelerometers were adjusted for each individual's weight, height, and date of birth. Physical activity (PA) and sedentary time were recorded using Actigraph GT3X+ accelerometers (Actigraph Corp. Pensacola, FL). Accelerometers were positioned above the right hip at the iliac crest, attached using an elastic belt. To ensure the correct placement of the device, participants were fitted with the accelerometer before leaving the testing session. Participants were instructed to wear the device for 7 consecutive days during waking hours, except for water-based activities. Two reminder telephone calls were made to the parents (one on a weekday and one on a weekend day) to ensure consistent adherence to the instructions. Devices were set to record data at a

sampling rate of 30 Hz, which was integrated into 15 sec epochs for analyses. Periods of zero values for more than 60 minutes were considered non-wear time (Tudor-Locke, Camhi & Troiano, 2012). Valid wear time was at least four days with ≥ 10 hours of wear time, including one valid weekend day (Colley, Gorber & Tremblay, 2010). Vector magnitude counts per minute (VM CPM) and steps per day were used to assess the total volume of PA and Freedson population-specific cut-points for children (Freedson, Pober & Janz, 2005) were applied: SB ≤100 cpm, light PA (LPA) 101–2.219 cpm, moderate PA (MPA) 2.220–4.135cpm, and vigorous PA (VPA) ≥4.136 cpm. ActiLife software v6.13.4 (Actigraph, Pensacola, FL, USA) was used for data processing. Sedentary bouts were defined as periods of 10 consecutive minutes below the SB cut-point of 100 cpm (drop time: 2 minutes). Sedentary patterns were defined as how children accumulate their SB, i.e., frequency and average length of sedentary bouts of 10 minutes minimum and how much time children spend in these bouts. The proportion of time spent in different PA intensities and sedentary bouts is reported to facilitate comparisons between time periods whilst taking wear time into account.

Statistical Analysis

Descriptive statistics (means ± SD) were applied for participant characteristics and differences between 2014 and 2021 were calculated using the independent-samples T test. Participants were divided into 2 age groups, group A 8-9 years old, and group B 10-11 years old, and the proportion of children meeting PA recommendations by age group and gender was estimated. PA and SB variables were adjusted for accelerometer wear time. Data sets were examined for normal distributions. Two (time points) by two (genders) factorial ANOVA models were tested separately for each PA metric. Results are reported at the level of significance $p < .001$, $p < .01$ and $p < .05$, and partial eta-squares (η^2) were calculated to assess the effect size.

Results

Participant characteristics and proportion meeting MVPA guidelines

Participant's characteristics are presented in Table 1. For both genders, no significant differences in weight, height and BMI were observed between the two time periods.

Table 1. Descriptive characteristics of the sample

Boys	2014	2021	p
N	34	48	
Age [years]	8.9±1.1	9.2±1.2	.143
Weight [kg]	37.9±6.1	39.9±9.3	.252
Height [m]	1.45± .07	1.46± .10	.570
BMI	18.1±2.0	18.7±3.2	.304
Girls	**2014**	**2021**	**p**
N	34	28	
Age [years]	9.4±1.4	9.8±1.2	.228
Weight [kg]	41.3±10.7	42.1±12.3	.780
Height [m]	1.47± .09	1.49± .11	.505
BMI	18.7±2.5	18.7±3.8	.945

Values are expressed as means ± standard deviation

BMI=body mass index

The percentage of children meeting the MVPA recommendations (>60 min/day) in 2014 and 2021 was 38,2 % and 40,8 %, respectively. In 2014, the percentage was 47 % for boys and 29,4 % for girls. In 2021, the percentage was 47,9 % for boys and 28,6 % for girls. The percentage of younger children (8-9 years) meeting MVPA guideline was 47 % in 2014 and 47,5 % in 2021. In 10-11 years, old children the percentage was 29,4 % in 2014 and 33,3 % in 2021.

Temporal changes in PA patterns

Table 2 presents the means and standard deviations of PA patterns for each time-point. There were no significant interaction effects of time points and gender on PA metrics. A simple main effect of time point was observed for LPA, which was significantly lower in 2021 compared to 2014 ($F_{(1,140)} = 7.220$, $p<.01$, $\eta^2=.05$). No significant main effects of time point were observed for MPA, VPA, daily MVPA, VM CPM and steps per day.

Table 2. Temporal changes in physical activity patterns from 2014 to 2021

	2014			2021		
	Boys (N=34)	**Girls** (N=34)	**Total** (N=68)	**Boys** (N=48)	**Girls** (N=28)	**Total** (N=76)
LPA (% wear-time)	33.9±6.0	32.1±8.5	**33.0±7.4****	30.2±5.2	29.9±5.6	**30.1±5.3****
Moderate PA (% wear-time)	4.99±1.45	3.99±1.46	4.49±1.53	4.61±1.52	4.06±1.26	4.40±1.45
Vigorous PA (% wear-time)	2.02±1.04	1.43± .85	1.73± .99	2.21±1.41	1.89±1.29	2.09±1.37
MVPA/day	58.6±19.3	45.7±17.3	52.2±19.3	60.1±25.2	51.6±20.3	57.0±23.7
VM CPM	1127±233	908±288	1017±283	978±236	891±264	946±249
Steps/day	10655±2358	9312±2444	9983±2477	10040±3102	9091±1838	9690±2731

Values are expressed as means ± standard deviation

LPA=light physical activity, MPA=moderate physical activity, VPA=vigorous physical activity, MVPA=moderate to vigorous physical activity, VM CPM=vector magnitude counts per minute, **p<.01

Temporal changes in SB patterns

Table 3 presents the means and standard deviations of SB patterns for each time-point. A significant interaction of time point and gender was observed only in the average length of sedentary bouts ($p< .05$). The post hoc analysis showed that the average length was significantly increased in 2021 compared to 2014 only in girls ($F_{(1,140)} = 5.935$, $p<.05$, $\eta^2=.04$). A significant main effect of time point was observed in the percentage of SB ($F_{(1,140)} = 4.365$, $p<.05$, $\eta^2=.03$) and the number of sedentary bouts per day ($F_{(1,140)} = 21.167$, $p<.001$, $\eta^2=.13$), both of which were higher in 2021 compared to 2014. No main effect of time point was observed in time in sedentary bouts per day and percentage of time in sedentary bouts.

Table 3. Temporal changes in Sedentary Behavior patterns from 2014 to 2021

	2014			2021		
	Boys (N=34)	**Girls** (N=34)	**Total** (N=68)	**Boys** (N=48)	**Girls** (N=28)	**Total** (N=76)
Total SB (% wear-time)	59.1±7.1	62.5±10.0	**60.8±8.8***	63.0±6.7	64.1±7.1	**63.4±6.8***
Number of SBouts/day	20.4±4.1	20.0±4.7	**20.2±4.4*****	23.9±4.4	23.6±4.7	**23.8±4.5*****
Time in SBouts/day (min)	374±104	429±168	402±141	442±102	443±106	442±102
Time in SBouts (% wear-time)	44.5±11.2	48.8±14.3	46.7±12.9	50.2±10.1	50.6±10.9	50.4±10.3
Average length of SBouts (min)	18.5±2.3	**18.6±2.2***	18.5±2.3	18.2±3.1	**21.5±8.3***	19.9±6.4

Values are expressed as means ± standard deviation. SB=sedentary behavior, SBouts=sedentary bouts. *p<.05, ***p<.001

Discussion

To the authors' knowledge, this is the first study to examine temporal trends in accelerometer-measured PA and SB patterns among school-aged children in Greece. These changes were examined within seven years and under the potential influences of the COVID-19 pandemic on daily routines. Overall, results indicate that there are important changes in children's PA and SB patterns from 2014 to 2021, even though total PA volume has remained fairly stable. Regarding the proportion of sufficiently active kids, less than one in three girls accumulated an average of 60 min/day, MVPA, while the percentage was higher in boys (more than 40%). This is in line with previous findings showing that girls are consistently less active (Konstabel, Veidebaum, Verbestel, Moreno, Bammann, Tornaritis et al., 2014), while Greek girls in particular are reportedly among the least active in Europe (Steene-Johannessen et al., 2020). The results indicate that the percentage of children meeting the PA recommendations has slightly increased, by two percentage points, from 2014 to 2021. Worldwide, recent studies indicate that the proportion of sufficiently active children may have declined (Steene-Johannessen, Anderssen, Kolle, Hansen, Bratteteig, Dalhaug, et al., 2021; Sasayama & Adachi, 2020). Cultural differences and the extent to which physical activity policies are developed and prioritized may influence physical activity levels in children (Steene-Johannessen et al., 2021).

On the contrary, our results indicate that the total volume of PA (steps per day and counts per minute) of Greek children hasn't significantly changed from 2014 to 2021. Our findings corroborate recent pedometer-based research, showing stable or declining levels of steps per day over the last 10 years (Cameron, Craig, Bauman & Tudor-Locke, 2016). A recent systematic review also detected secular declines in the total volume of physical activity in children and adolescents (Conger, Toth, Cretsinger, Raustorp, Mitáš, Inoue, et al. 2022). The present data also showed a temporal trend for a decrease in light PA. In contrast, there was a significant trend for an increase in the percentage of total daily SB. Opportunities for sedentary activities seem to be ever-increasing in school-age children (Steene-Johannessen et al., 2021). The trend toward greater use of technology has enabled children to alter the way they perform educational activities or play (Lim & Oakley, 2013). Over the past decade, the advent of available and affordable technology and digital communication is considered to have fundamentally changed the way children engage in SB (Dalene et al., 2022). In addition, COVID-19 has caused unprecedented disruption to children's and adolescents' lifestyles (Hurter, McNarry, Stratton & Mackintosh, 2022). The majority of studies examining changes in PA and SB as a result of Covid-19 pandemic reported decreases in PA and increases in SB, compared to pre-pandemic, in several countries (Burkart, Parker, Weaver, Beets, Jones, Adams, et al., 2022; Dallolio, Marini, Masini, Toselli, Stagni, Bisi, et al., 2022; Salway, Foster, de Vocht, Tibbitts, Emm-Collison, House, et al., 2022; Ten Velde et al., 2021). It is therefore possible that these factors have contributed to the observed secular increase in ST and decrease in LPA.

Regarding higher intensity PA, MVPA did not change markedly between 2014 and 2021. This is in line with previous studies that have considered trends of accelerometer-measured MVPA and indicate that MVPA levels may have remained relatively stable (Reilly et al., 2022; Steene-Johannessen et al., 2021; Dalene, Anderssen, Andersen, Steene-Johannessen, Ekelund, Hansen, et al., 2018; Colley, Carson, Garriguet, Janssen, Roberts & Tremblay, 2017). MVPA is often connected to young people's recreational hobbies and sports outside school (Mathisen, Kokko, Tynjälä, Torsheim & Wold, 2019). Perhaps, the strong public concern regarding low levels of PA among children,

especially during the Covid-19 pandemic, has made parents regard sports participation as a major solution to promote their children's physical activity levels and consequently their health.

Independent of time spent in MVPA, both the total volume and pattern of SB have been shown to influence health and development in children (Cliff, Hesketh, Vella, Hinkley, Tsiros, Ridgers, et al., 2016). It is important to consider that even children meeting PA recommendations may not be protected against the health detriments of engaging in excessive SB (Bates et al., 2020). Studies in adults have shown that less fragmentation of sedentary time (longer bouts) is associated with obesity and other health indicators, although research involving children has been less conclusive (Fraysse, Grobler, Muller, Wake & Olds, 2019). In this study, the aim was to examine the 7-year temporal trends of accelerometer-based SB patterns. According to the results, the percentage of SB accumulated in bouts was significantly higher in 2021 compared to 2014. In addition, the results indicate a significant trend for an increase in the number of bouts per day. Notably also, whereas trends for increase in total SB were similar in boys and girls, changes in SB accumulation patterns as expressed by the average length of sedentary bouts, were more pronounced in girls. Existing cross-sectional studies also found that girls engaged in more SB than boys (Pereira, Cliff, Sousa-Sá, Zhang & Santos, 2019; Bailey, Charman, Ploetz, Savory & Kerr, 2017). To the best of our knowledge, no previous study had examined the temporal trends of accelerometer-measured SB patterns in Greek children over a similar time period. Future research is needed to confirm our findings.

An abundance of studies has indicated that prolonged SB in children and adolescents has become a big concern (Verloigne, Van Lippevelde, Maes, Yıldırım, Chinapaw, Manios, et al., 2012). Part of the increased SB may be due to school curricula demanding academic requirements (Zhang, Li, Slapsinskaite, Zhang, Zhang & Gui, 2020). Lifestyle changes related to the COVID-19 pandemic along with the inconsiderate use of technology may have worsened many aspects of a child's sedentary behavior (Bates et al., 2020). However, it is currently not clear what constitutes a long period of sitting time in children and it is essential to increase our understanding of children's sedentary patterns.

Strengths and limitations

This study was the first to examine the temporal change of PA and SB patterns measured by accelerometry in children in Greece. Actigraph GT3X+ accelerometers are an accurate and valid method for PA assessment. The two cohorts were from the same geographic region and had similar characteristics concerning participants' age/school year, ethnicity, and health status. Accelerometer-assessed PA has certain limitations such as underestimation of PA levels associated with activities such as swimming, cycling, and load-bearing. Moreover, the data is cross-sectional meaning that we cannot account for past PA habits. Finally, our study is not based on national representative data.

Conclusion

In conclusion, from 2014 to 2021 there had been a change in PA and SB patterns in school-aged children, namely a substitution of light PA with SB, although MVPA and total PA volume did not appear to have changed significantly. Additionally, our data suggest that at least for girls, sedentary pursuits are more prolonged than before. In terms of the proportion of children meeting the activity guidelines, fewer than one in three girls managed to achieve an average of 60 minutes per day of MVPA, whereas the percentage was higher among boys, with over 40% meeting this benchmark. The trend towards an increase in children's SB over time, as well as the high proportion of children not meeting MVPA guidelines are concerning, as they have been linked to a range of negative health outcomes, including obesity, cardiovascular disease and bone health problems. This highlights the need for targeted efforts to encourage and facilitate PA among girls, addressing barriers and promoting inclusive opportunities for all children to lead active and healthy lives. Future research should continue to investigate these patterns to inform targeted interventions aimed at promoting active lifestyles and reducing sedentary behaviors, especially among girls, in the face of evolving societal and environmental influences.

Conflicts of interest - The authors declare that there is no conflict of interest.

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