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Article

Association between Temperature and Sunlight Hours with Daily Steps in School-Aged Children over 35 Weeks: Findings from the e-MOVI Study

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Abstract: Objective: To examine the dose-response relationship between average daily temperature and sunlight hours with daily steps across a 35-week period in school-aged children, and to evaluate whether there were differences by sex. Methods: We conducted a follow-up study involving 655 children (50.8% girls, mean age 10.45 ± 0.95) from six public primary schools in Cuenca, Spain. We measured daily steps using Xiaomi Mi Band 3 Smart Bracelets from October 2022 to June 2023 (over 35 weeks). We collected daily average temperature from the local weather station in Cuenca and sunlight hours during the same period. We used ANCOVA models and LOESS regression to examine the dose-response relationship between average daily temperature and daily hours of sunlight with daily steps. Additionally, we performed a multiple linear regression model. Results: Our findings revealed significant variations in daily steps across the 35 weeks. The relationship between environmental factors and daily steps was non-linear, in both girls and boys. The optimal values for higher activity levels were an average temperature of 14°C and 13 hours of sunlight. Furthermore, a 1 °C increase in temperature was associated with an increase of 74 ± 130 steps/day, while an increase of one hour of sunlight was associated with an increase of 315 ± 237 steps/day. However, sunlight hours may act as a moderating factor. Conclusion: Our study showed a non-linear association between average daily temperature and sunlight hours with daily steps over a 35-week period. Additional strategies may be necessary to encourage increased physical activity during periods of extreme temperatures or sunlight exposure.

Keywords: children; sunlight; temperature; daily steps; physical activity; dose-response analysis

1. Introduction

Physical activity (PA) is a crucial component of healthy development in school-aged children, contributing to physical fitness [1], mental well-being [2], and the prevention of non-communicable diseases, such as heart disease, type 2 diabetes, and cancers in adulthood [3]. However, PA levels among children have declined considerably in recent decades [4,5], raising global concern about the public health implications [6]. Physical inactivity has been observed to further increase as children enter adolescence, with PA levels reducing at an average rate of 7% per year between the ages of 10

and 19 years [7]. Understanding the determinants of daily PA is essential for designing effective interventions aimed at promoting active lifestyles among youth.

Environmental factors, particularly weather conditions, have been identified as significant influences on PA behaviours [8]. In this regard, the available evidence suggests that there is a seasonal variation in PA, with children being more active during the spring and summer months compared to the autumn and winter months [9]. Temperature, one of the most influential weather conditions, can affect children's willingness and ability to engage in outdoor activities, as demonstrated by a recent meta-analysis that reported positive associations between temperature and PA [8]. However, the findings are inconsistent, as the relationship between temperature and moderate-vigorous physical activity (MVPA) and total PA is curvilinear in Australian and American children [10,11], respectively, whereas in Spain and France, higher temperatures have been linearly associated with significantly higher MVPA levels [12]. In the case of daylight hours, some studies reported higher overall PA during longer duration of sunlight [10,13,14], however one study found negative associations [15].

Although daily step counts have emerged as a practical and easily quantifiable metric for assessing the activity levels of children in both research and real-world settings [16,17], few studies have studied the association of weather conditions with this measure as an objective metric of PA [18,19]. Furthermore, most studies have been conducted over relatively short periods of time, often assessing PA for a period of seven days or less or comparing specific seasonal periods, which could contribute to bias because the data are collected in a restricted period of the year. Thus, there is limited evidence on how daily variations in temperature and sunlight hours impact PA levels, such as daily steps, in children over a prolonged period. Therefore, it was essential to ascertain the impact of different temperature thresholds and sunlight hours on the daily step count, and to determine whether there is a non-linear relationship. This study aimed to examine the dose-response relationship between daily steps and average daily temperature and sunlight hours across a 35-week period in school-aged children and to evaluate whether there were differences by sex.

2. Methods

2.1. Study Design and Participants

Following the STROBE guidelines [20] (Table S1), we performed prospective longitudinal analyses of data from the e-MOVI study, in which PA, dietary behaviour, lifestyle, and cardiovascular risk were evaluated during childhood. Data collection began in October 2022 (yearly week 41) and ended in June 2023 (yearly week 23), lasting 35 weeks. Each child was followed for 28 weeks, as data collection did not start simultaneously for all subjects.

One thousand and forty-nine children aged 9 to 12 years old, in 4th, 5th or 6th grade, from 6 public primary schools in the province of Cuenca, Spain, were invited to participate in the research project. In order to participate in e-MOVI, the children had to meet the following criteria: i) they had to have literacy in Spanish (or Spanish sign language), ii) not have serious learning difficulties or physical and mental disorders that could prevent their participation; iii) not have allergies to the materials used in the smart wristband; iv) and have consent from their parents or legal guardians to participate in the research project. A total of 745 (71.0%) schoolchildren were enrolled in the study. Out of the total sample, 655 children (62.4%) were included in the present analyses as 85 (0.8%) were excluded due to missing data on daily step counts for all weeks (Figure S1).

2.2. Study Area

This study was conducted in the province of Cuenca, Spain, which is situated in the central region of the Iberian Peninsula, the southernmost peninsula of the European continent. The villages considered for the study were Iniesta, Motilla del Palancar, San Clemente, Quintanar del Rey, Mota del Cuervo, and Las Pedroñeras (Figure S2). The main characteristics of the villages considered in the present study are shown in Table S2.

Their location, altitude, and proximity to the sea result in a temperate continentalised Mediterranean climate, which is characterised by warm summers and cold winters [21]. Additionally, the duration of sunlight in Spain fluctuates throughout the year due to the country's geographical location and seasonal changes. Spain is situated in the Central European Time Zone in winter and in the Central European Summer Time in summer, and its position in the southwestern region of Europe also impacts the duration of sunlight. In the summer months (June to September) the days have more sunlight hours, while in the winter months (December to February) the days have fewer sunlight hours. The longest day of the year occurs during the summer solstice, around 21 June, while the shortest day occurs during the winter solstice, around 21 December. The study areas experienced a mean of 9.35 hours and 14.90 hours of sunlight on the shortest day in 2022 and on the longest day in 2023, respectively.

2.3. Study Variables

2.3.1. Exposure: Environmental Factors

2.3.1.1. Daily Sunlight Hours

The mean daily sunlight hours were calculated for each week. Sunlight hours were defined as the time between sunrise and sunset. For each village, specific sunlight hours were determined.

2.3.1.2. Average Daily Temperature

The mean of the daily average temperature (°C) was calculated for each week. The daily average temperature was obtained from the meteorological data of the Spanish State Meteorological Agency (AEMET, <https://www.aemet.es/>) of the Cuenca weather station, located in the city of Cuenca at an altitude of 956 metres above sea level. The mean distance from the participants' villages to the weather station was 77.9 km (range from 59.1 km to 82.7 km).

2.3.2. Outcome: Daily Steps

Participants wore a Xiaomi Mi Band 3 Smart Bracelet on their nondominant wrist to measure daily steps. This device has been validated for daily step counts [22]. The mean number of daily steps per week was calculated for participants whose wristbands had records for at least 4 days per week, including at least 1 weekend day. The children recorded their daily steps, showed by the wristband, in a log, which was collected weekly at school by a member of the research team.

2.4. Statistical Analysis

Statistical (Kolmogorov-Smirnov test) and graphical methods (normal probability plots) were used to assess the normality of all continuous variables. The characteristics of the study sample were compared by sex using Student's t-test. Homogeneity of variances was assessed with the Levene test. For the remaining analyses, we used the 35 weeks of follow-up (from week 41 2022 to week 23 2023) as units of observation instead of the study subjects. Each week represented the mean of the schoolchildren for each of the variables analysed, stratified by sex.

To explore the relationship between weeks of the year and daily steps, average daily temperature, and daily sunlight hours, we used a locally weighted scatterplot smoothing (LOESS) regression. We also used LOESS regression to examine the relationship among daily steps, daily hours of sunlight and average daily temperature.

We used analysis of covariance (ANCOVA) models to analyse the mean differences in daily steps as dependent variable by average daily temperature tertiles (< 8.8 °C, 8.8-13.7 °C, and >13.7 °C) and by daily sunlight hours tertiles (< 10 hours, 10-12 hours, and > 12 hours) -model 0-, and controlling for daily sunlight hours and average daily temperature, respectively -model 1-. For significant associations, eta-squared values were also provided [23]. Additionally, we examined the interaction between average daily temperature and daily sunlight hours.

We performed a multiple linear regression model to estimate the linear association between average daily temperature and daily sunlight hours with daily steps -model 0- and adjusting for average daily temperature and daily sunlight hours, respectively -model 1-.

For subjects with missing daily step data, we performed data imputation to make the most of the available information and maintain statistical power. Multiple imputation is an approach used to compensate for missing data based on an automatic chained method selected through comprehensive data analysis. This involved generating five replications, which were subsequently pooled together in the analysis [24].

Analyses were conducted using the statistical software package IBM SPSS Statistics 29.0 (SPSS, Inc., Chicago, IL, USA) and JASP 0.18.3 software (University of Amsterdam, Amsterdam, The Netherlands). The statistical significance was set at two-tailed $p < 0.05$.

2.5. Ethics

The study protocol received was approved by the Clinical Research Ethics Committee of the Hospital Virgen de la Luz de Cuenca (REG: 2019/PI1519). Following approval from the Governing Board of each school, a letter was sent to the parents of all grade students inviting them to a meeting. During this meeting, the study's objectives were explained, and written consent was requested for their children's participation. Furthermore, the study's characteristics were explained to the schoolchildren, who provided their consent to participate. After data collection, parents were informed of their children's results by letter. All procedures conducted in this study adhered to the Declaration of Helsinki and its subsequent amendments or equivalent ethical standards for experiments involving human participants.

3. Results

Table 1 shows the descriptive characteristics of the study participants (mean $\pm$ standard deviation). A total of 655 children were included in the study, with a mean age of 10.45 ± 0.95 years, of whom 333 (50.8%) were girls. There were statistically significant differences between boys and girls in daily steps. Table S3 presents the number of children followed-up each week, along with the mean and standard deviation for daily steps, daily sunlight hours, and average daily temperature.

Table 1. Characteristics of the study sample and environmental conditions.

	Total (n = 655)	Girls (n = 333)	Boys (n = 322)	p-value
Age (year)	10.45 $\pm$ 0.95	10.51 $\pm$ 0.96	10.38 $\pm$ 0.94	0.088
Weight (kg)	39.22 $\pm$ 10.36	39.71 $\pm$ 10.63	38.71 $\pm$ 10.07	0.217
Body mass index, kg/m ²	18.85 $\pm$ 3.76	18.89 $\pm$ 3.77	18.80 $\pm$ 3.75	0.757
Daily steps	11,279 $\pm$ 3,029	10,189 $\pm$ 2,631	12,406 $\pm$ 3,006	<0.001
Average weekly temperature (°C) exposure	11.50 $\pm$ 4.98	11.50 $\pm$ 4.98	11.50 $\pm$ 4.98	-
Daily sunlight hours exposure	11.44 $\pm$ 1.83	11.44 $\pm$ 1.83	11.44 $\pm$ 1.83	-

Values are mean $\pm$ standard deviation. The values in bold indicate statistical significance at $p < 0.05$.

Figure 1 depicts the trend of the association between weeks of the year and daily steps, average daily temperature, and daily sunlight hours. In December, the number of daily steps and the number of sunlight hours coincided at their lowest point, and both increased from January onwards. However, there was a decline in daily steps from April (week 15, 12,416 $\pm$ 4,820) , while the number of sunlight hours continued to increase. Meanwhile, the temperature followed the same pattern as the sunlight hours, although it was lower in January and February. Consistently, daily steps exhibited a similar trend for both boys and girls throughout the year (Figure S3).

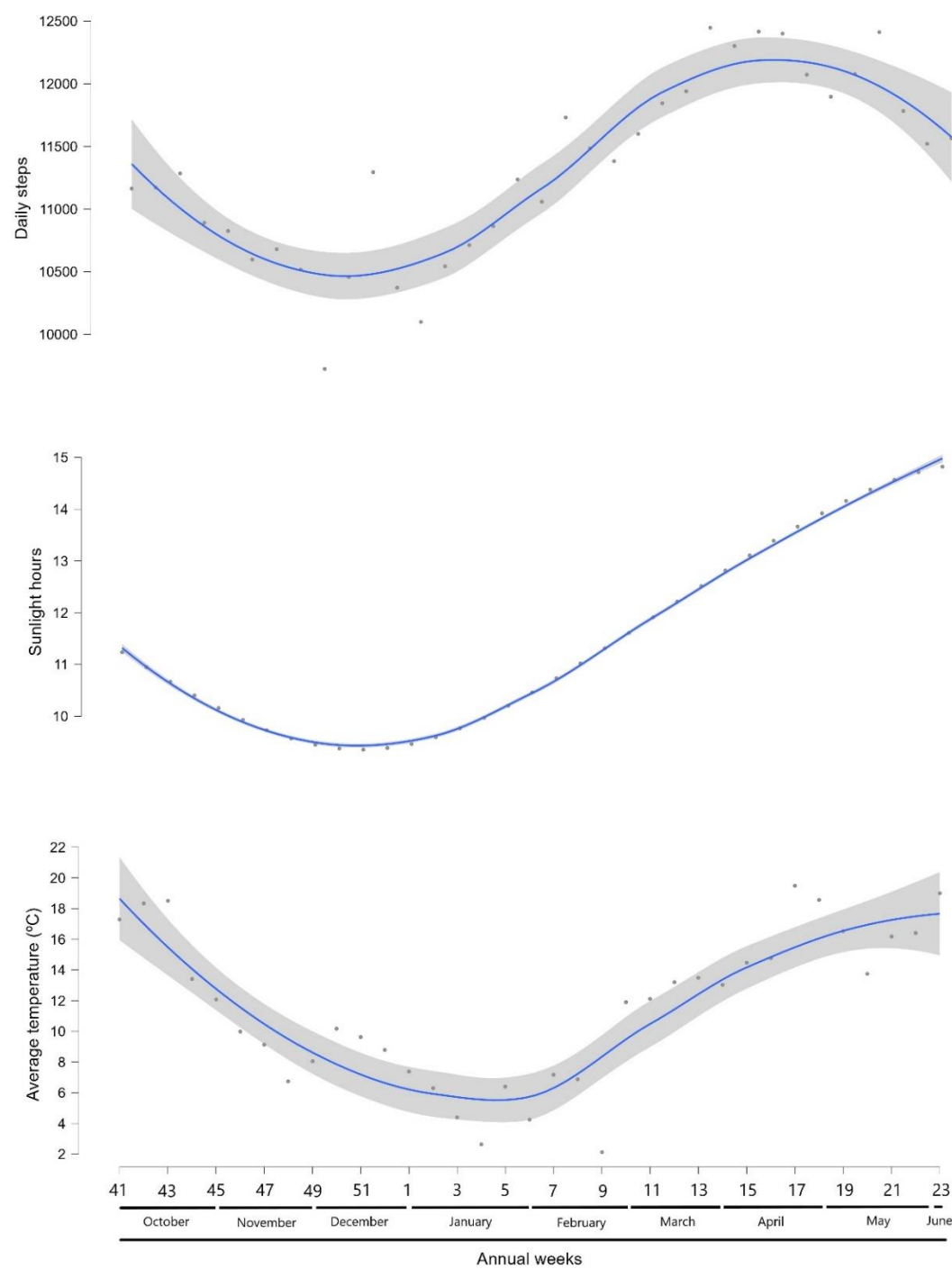


Figure 1. Scatterplots illustrating LOESS regression analysis between weeks of the year (from week 41 2022 to week 23 2023) and daily steps, average daily temperature (°C), and daily sunlight hours. Complete n (n = 655): Week 49 to Week 17.

Figure 2 shows that the relationships between average daily temperature and daily sunlight hours with daily steps were non-linear. However, the relationship between average daily temperature and daily sunlight hours was linear (Figure S5). The number of daily sunlight hours associated with the highest number of daily steps appears to be around 13 hours, in both girls and boys (Figure S4). Additionally, the number of daily steps increased as the average daily temperature was between 10°C and 14°C, and decreased again from 14°C onwards, except for boys, where it plateaued (Figure S4).

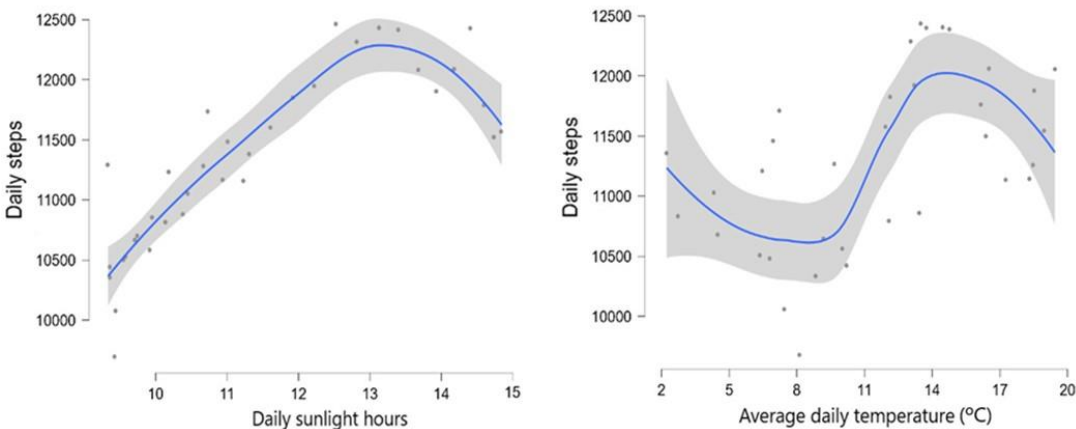


Figure 2. Scatterplots illustrating LOESS regression analysis between daily steps and average daily temperature (°C) and daily sunlight hours.

Based on the ANCOVA models, it was found that the number of daily steps taken by both girls and boys increased with an increase in average daily temperature (Table 2). However, significant differences were only observed between temperatures < 8.8 °C and > 13.7 °C for the total sample and in boys, and between 8.8-13.7 °C and > 13.7 °C in girls (model 0). When the ANCOVA models were adjusted for daily sunlight hours (model 1), the differences disappeared, except for girls, who were found to take fewer steps when the temperature was > 13.7 °C.

Table 2. Analysis of covariance of daily steps (total sample, girls, and boys) by average daily temperature (°C) categories for 35 weeks.

		Average daily temperature categories			p-value	eta square
		Low (L) <8.8 °C	Medium (M) 8.8-13.7 °C	High (H) >13.7 °C		
	n weeks	12	11	12		
Daily steps total sample	M ₀	10,810 ± 597 ^H	11,352 ± 712	11,813 ± 475 ^L	<0.001	0.346
	M ₁	11,295 ± 509	11,541 ± 434	11,154 ± 575	0.159	0.112
Daily steps girls	M ₀	9,643 ± 547 ^H	10,233 ± 907	10,840 ± 785 ^L	0.002	0.319
	M ₁	10,345 ± 527	10,507 ± 448 ^H	9,888 ± 592 ^M	0.042	0.185
Daily steps boys	M ₀	12,016 ± 657 ^H	12,503 ± 568	12,892 ± 384 ^L	0.002	0.325
	M ₁	12,294 ± 603	12,611 ± 514	12,515 ± 679	0.352	0.065

Data are presented as mean ± standard deviation (SD). The values in bold indicate statistical significance at $p < 0.05$. Model 0 (M₀): raw data analysis. Model 1 (M₁): controlling for daily sunlight hours. Superscript letter indicates statistical significance ($p < 0.05$) between categories for post-hoc tests using the Bonferroni comparisons. Eta squared values of 0.01, 0.06, and 0.14 indicate small, intermediate, or strong effect size respectively.

Similarly, the number of daily steps taken by both girls and boys was found to increase with increasing daily sunlight hours, as indicated by ANCOVA models (Table 3). However, no significant difference was observed between 10-12 hours and > 12 hours of daily sunlight for boys (model 0). This finding remained significant after controlling for average daily temperature (model 1).

Table 3. Analysis of covariance of daily steps (total sample, girls, and boys) by daily sunlight hours categories for 35 weeks.

		Daily sunlight hours categories			p-value	eta square
		Low (L) <10h	Medium (M) 10-12h	High (H) >12h		
	n weeks	11	12	12		
Daily steps	M ₀	10,533 ± 403 ^{M,H}	11,306 ± 317 ^{L,H}	12,069 ± 334 ^{L,M}	<0.001	0.774
total sample	M ₁	10,446 ± 408 ^{M,H}	11,292 ± 350 ^{L,H}	12,162 ± 423 ^{L,M}	<0.001	0.710
Daily steps	M ₀	9,354 ± 295 ^{M,H}	10,036 ± 483 ^{L,H}	11,254 ± 422 ^{L,M}	<0.001	0.799
girls	M ₁	9,185 ± 451 ^{M,H}	10,010 ± 385 ^{L,H}	11,436 ± 468 ^{L,M}	<0.001	0.779
Daily steps	M ₀	11,748 ± 523 ^{M,H}	12,636 ± 275 ^L	12,963 ± 389 ^L	<0.001	0.632
boys	M ₁	11,775 ± 481 ^{M,H}	12,640 ± 412 ^L	12,935 ± 499 ^L	<0.001	0.489

Data are presented as mean ± standard deviation. The values in bold indicate statistical significance at p < 0.05. Model 0 (M0): raw data analysis. Model 1 (M1): controlling for average daily temperature (°C). Superscript letter indicates statistical significance (p < 0.05) between categories for post-hoc tests using the Bonferroni comparisons. Eta-squared values of 0.01, 0.06, and 0.14 indicate small, intermediate, or strong effect size respectively.

Furthermore, we observed that there was interaction effect between daily sunlight hours and average daily temperature (p < 0.001). In this sense, Figure S6a shows that there was no significant variation in the number of daily steps between temperature tertiles as a function of sunlight hours tertiles. Although conversely (Figure S6b), in each tertile of average daily temperature, the number of daily steps was observed to be higher when sunlight hours were higher. This was similar for girls and boys, except for the temperature tertile > 13.7°C, where boys had no difference in daily sunlight hours (Figure S7).

Finally, an increase of one hour of daily sunlight was associated with an increase of 315 ± 237 steps/day (416 ± 260 steps/day in girls and 235 ± 278 steps/day in boys; p < 0.001). Meanwhile, an increase of 1°C of average daily temperature was associated with an increase of 74 ± 130 steps/day (86 ± 166 steps/day in girls and 69 ± 112 steps/day in boys; p < 0.05). However, after adjusting for daily sunlight hours and average daily temperature, respectively, the linear regression only remained significant for daily sunlight hours (Table S4).

4. Discussion

Our findings revealed significant variations in daily steps across the 35 weeks in Spanish children. We observed that the relationship between daily steps and environmental factors was non-linear, in both girls and boys. The optimal values for higher activity levels were identified as an average temperature of 14°C and 13 hours of sunlight per day. However, the relationship of average temperature and daily steps is moderated by the number of sunlight hours. Furthermore, an increase of one hour of daily sunlight was associated with an increase of 315 ± 237 steps/day.

The children's daily step counts showed fluctuations across the academic year, exhibiting a pattern comparable to that observed in previous studies, with the highest levels of PA, including daily steps, in spring and the lowest in winter [9,25]. The observed seasonal variations in PA can be attributed to the environmental factors inherent to the respective seasons [26], since in spring and summer, for instance, there is an increase in daylight hours and a rise in the average daily temperature compared to winter and autumn, which could make the practice of PA more comfortable. However, day-to-day variation in weather within seasons can also have an impact on PA. In this regard, our results are consistent with previous studies in which higher PA was observed with higher temperature [10,19,27] and sunlight hours [10,13,14], including earlier research also conducted in Spanish children [12]. Nevertheless, the non-linear relationships identified in our study indicate a decline of daily steps when an average temperature of 14°C and 13 hours of sunlight are

reached. Similarly, in Australian and American children the relationships between PA and temperature were curvilinear, and the optimal physical levels occurred at maximum temperatures between 20 °C and 25 °C [10,27], and at an average temperature of 20 °C [11], respectively. This suggests that the results are relative, depending on the type of climate in each country or region.

The time spent outdoors is a significant predictor of overall PA levels in children, as it is generally spent in more physically active behaviours than time spent indoors [28]. Children are more active when the weather is more conducive to outdoor activity [29]. The observed plateau in boys or decline in girls in activity at higher temperatures observed in our cohort may be indicative of a threshold beyond which children, particularly girls, reduce their outdoor activity due to discomfort or safety concerns related to excessive heat. The reduction in daily steps on days with > 13 hours of sunlight may be attributed to children engaging in other activities that do not necessarily involve movement, such as social activities or the use of electronic devices, or academic-related activities. The findings of Ren et al. [30] indicate that the increase in sedentary time can be attributed to excessive homework during weekdays. In our case, the days of maximum sunlight hours coincided with the end of the school year, when final exams are concentrated, leading to an increase in study time. However, these hypotheses require confirmation and additional research to elucidate the underlying mechanisms responsible for this inverted U-shaped relationship.

Notably, we found a significant interaction between sunlight hours and temperature for the mean difference in daily steps. Thus, children accumulated more daily steps on days with more sunlight hours, irrespective of the average temperature. This suggests that sunlight hours may act as a moderating factor in the relationship between temperature and daily steps. This finding aligns with the hypothesis proposed by Beighle and colleagues [26], suggesting that children may remain active in colder climates if they have access to longer daylight hours, simply because they have more hours to be outside. However, contrary to our findings, Duncan et al. [18] observed that the relationship between temperature and daily steps was independent of daylength in New Zealand children, while the association of daylength with daily steps was unclear after adjustment for the temperature. These observed differences may be attributed to variations in the geographical context or the duration of the follow-up period, given that the study was conducted between August and December (winter to summer).

The findings from this study emphasize the importance of assessing PA over extended periods, since short-term studies or those focused on a specific season may not capture the full complexity of the variability in children's activity levels in response to environmental factors. By examining these associations over a 35-week period, our study provides a more comprehensive understanding of the impact of daily variations in temperature and sunlight on physical activity. This long-term perspective is crucial for the development of physical activity programmes that are effective throughout the entire school year, rather than only during optimal weather conditions. Furthermore, additional strategies may be necessary to encourage increased physical activity during periods of extreme temperatures or during periods of shorter sunlight.

Strengths and Limitations

The study has several limitations that must be acknowledged. Firstly, the observational nature of the study limits our ability to infer causality between environmental factors and PA. Although we observed significant associations, we could not definitively conclude that changes in temperature and sunlight hours caused changes in daily steps. Experimental studies would be needed to establish causal relationships. Secondly, although we considered daily variations in temperature and sunlight hours, other environmental factors, such as humidity, wind speed, and air quality, were not included in the analysis. Thirdly, the study was conducted in a specific geographical region (Spain), which may limit the generalisability of the findings to other climates or regions. Different regions may experience different environmental influences, and thus, caution should be exercised when applying these results to populations in other parts of the world with distinct climatic conditions. Finally, the data on daily steps was self-reported by the children, which could introduce the potential for reporting bias. However, we endeavoured to minimise bias and enhance reliability

through the implementation of a rigorous data collection procedure and providing clear instructions to the participants. Future studies should consider using objective measures to improve data reliability.

Despite these limitations, our study has several strengths that enhance the validity and generalisability of its findings. Firstly, the longitudinal design, which encompasses a period of 35 weeks, offers a comprehensive insight into the fluctuations in daily PA, as measured by step counts, in response to environmental variables over time. By collecting data across multiple seasons, we were able to mitigate the biases associated with seasonal variations that are commonly observed in studies with shorter durations. Secondly, the large sample size of 655 children allows for a robust analysis and the ability to detect meaningful differences in activity patterns, including sex-based variations.

5. Conclusions

Our study found that daily steps accumulated by both girls and boys increased with an increase in daily sunlight hours and average daily temperature over a 35-week period. However, these relationships were non-linear, and the highest number of steps was observed at an average temperature of 14°C and 13 hours of sunlight. A significant interaction between these two factors was observed, indicating that the relationship of average temperature and daily steps is moderated by the number of sunlight hours. These results highlight the need for tailored strategies to maintain or even enhance PA during periods of extreme temperatures or sunlight exposure, ensuring that children remain active regardless of the season. Further research is needed to assess how children's use of leisure time changes under varying environmental conditions.

Supplementary Materials: Table S1. STROBE Statement. Checklist of items that should be included in reports of longitudinal studies. Table S2. Characteristics of the study areas. Table S3. Daily steps, daily sunlight hours, and average daily temperature (°C), by week of the year and sex. Table S4. Multivariable linear regression model of daily steps (total sample, girls, and boys) and daily sunlight hours and average weekly temperature (°C) for 35 weeks. Figure S1. Diagram flow of the study participants in the current study, from the original e-MOVI project. Figure S2. Map of the study area. Figure S3. Scatterplots illustrating LOESS regression analysis between weeks of the year (from week 41 2022 to week 23 2023) and daily steps, average daily temperature (°C), and daily sunlight hours, by sex. Complete n (n girls = 333, n boys = 322): Week 49 to Week 17. Figure S4. Scatterplots illustrating LOESS regression analysis between daily steps and average daily temperature (°C) and daily sunlight hours, by sex. Figure S5. Scatterplots illustrating LOESS regression analysis between average daily temperature (°C) and daily sunlight hours. Figure S6. Interaction between average daily temperature and daily sunlight hours for the mean difference in daily steps. Figure S7. Interaction between average daily temperature and daily sunlight hours for the mean difference in daily steps by sex.

Author Contributions: Conceptualization, ERG and VMV; Methodology, ERG and ATC; Software, ERG and E.J.L.; Validation, VMV and NB; Formal Analysis, ERG and VMV; Investigation, AEM and VMV; Resources, VMV; Data Curation, AEM; Writing – Original Draft Preparation, ERG and ATC; Writing – Review & Editing, ATC, VMV, VDG, E.J.L., NB; Visualization, NB, MJGP, and VDG; Supervision, VMV and ATC; Project Administration, AEM, ERG, VMV; Funding Acquisition, VMV. .

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Clinical Research Ethics Committee of the Hospital Virgen de la Luz de Cuenca (REG: 2019/PI1519).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing Interests: The authors declare that they have no competing interests.

References

1. Wu, J.; Yang, Y.; Yu, H.; Li, L.; Chen, Y.; Sun, Y. Comparative Effectiveness of School-Based Exercise Interventions on Physical Fitness in Children and Adolescents: A Systematic Review and Network Meta-Analysis. *Front Public Health* 2023, 11, doi:10.3389/FPUH.2023.1194779.
2. Bermejo-Cantarero, A.; Sánchez-López, M.; Álvarez-Bueno, C.; Redondo-Tébar, A.; García-Hermoso, A.; Martínez-Vizcaino, V. Are Physical Activity Interventions Effective in Improving Health-Related Quality of Life in Children and Adolescents? A Systematic Review and Meta-Analysis. *Sports Health* 2023, doi:10.1177/19417381231190885.
3. Lee, I.-M.; Brigham And Women's Hospital, H.; Shiroma, E.J.; Lobelo, F.; Puska, P.; Blair, S.N.; Katzmarzyk, P.T. Effect of Physical Inactivity on Major Non-Communicable Diseases Worldwide: An Analysis of Burden of Disease and Life Expectancy. *Lancet* 2012, 380, 219–248, doi:10.1016/S0140-6736(12)61031-9.
4. Guthold, R.; Stevens, G.A.; Riley, L.M.; Bull, F.C. Global Trends in Insufficient Physical Activity among Adolescents: A Pooled Analysis of 298 Population-Based Surveys with 1·6 Million Participants. *Lancet Child Adolesc Health* 2020, 4, 23–35, doi:10.1016/S2352-4642(19)30323-2.
5. Farooq, A.; Martin, A.; Janssen, X.; Wilson, M.G.; Gibson, A.M.; Hughes, A.; Reilly, J.J. Longitudinal Changes in Moderate-to-Vigorous-Intensity Physical Activity in Children and Adolescents: A Systematic Review and Meta-Analysis. *Obesity Reviews* 2020, 21, e12953, doi:10.1111/OBR.12953.
6. Kohl, H.W.; Craig, C.L.; Lambert, V.; Inoue, S.; Alkandari, R.; Leetongin, G.; Kahlmeier, S. The Pandemic of Physical Inactivity: Global Action for Public Health. *Lancet* 2012, 380, 294–305, doi:10.1016/S0140-6736(12)60898-8.
7. Dumith, S.C.; Gigante, D.P.; Domingues, M.R.; Kohl, H.W. Physical Activity Change during Adolescence: A Systematic Review and a Pooled Analysis. *Int J Epidemiol* 2011, 40, 685–698, doi:10.1093/IJE/DYQ272.
8. Zheng, C.; Feng, J.; Huang, W.Y.; Wong, S.H.S. Associations between Weather Conditions and Physical Activity and Sedentary Time in Children and Adolescents: A Systematic Review and Meta-Analysis. *Health Place* 2021, 69, doi:10.1016/J.HEALTHPLACE.2021.102546.
9. Atkin, A.J.; Sharp, S.J.; Harrison, F.; Brage, S.; Van Sluijs, E.M.F. Seasonal Variation in Children's Physical Activity and Sedentary Time. *Med Sci Sports Exerc* 2016, 48, 449–456, doi:10.1249/MSS.0000000000000786.
10. Remmers, T.; Thijs, C.; Timperio, A.; Salmon, J.; Veitch, J.; Kremers, S.P.J.; Ridgers, N.D. Daily Weather and Children's Physical Activity Patterns. *Med Sci Sports Exerc* 2017, 49, 922–929, doi:10.1249/MSS.0000000000001181.
11. Quante, M.; Wang, R.; Weng, J.; Kaplan, E.R.; Rueschman, M.; Taveras, E.M.; Rifas-Shiman, S.L.; Gillman, M.W.; Redline, S. Seasonal and Weather Variation of Sleep and Physical Activity in 12–14-Year-Old Children. *Behavioral Sleep Medicine* 2019, 17, 398–410, doi:10.1080/15402002.2017.1376206.
12. Aibar, A.; Bois, J.E.; Generelo, E.; Bengoechea, E.G.; Paillard, T.; Zaragoza, J. Effect of Weather, School Transport, and Perceived Neighborhood Characteristics on Moderate to Vigorous Physical Activity Levels of Adolescents From Two European Cities. <http://dx.doi.org/10.1177/0013916513510399> 2013, 47, 395–417, doi:10.1177/0013916513510399.
13. Beghin, L.; Vanhelst, J.; Drumez, E.; Migueles, J.; Manios, Y.; Moreno, L.A.; De Henauw, S.; Gottrand, F. Influence of Meteorological Conditions on Physical Activity in Adolescents. *J Epidemiol Community Health* 2020, 74, 395–400, doi:10.1136/JECH-2019-212459.
14. Oliver, M.; Schluter, P.J.; Schofield, G.M.; Paterson, J. Factors Related to Accelerometer-Derived Physical Activity in Pacific Children Aged 6 Years. <http://dx.doi.org/10.1177/1010539510370992> 2010, 23, 44–56, doi:10.1177/1010539510370992.
15. Zheng, C.; Huang, W.Y.; Wong, S.H.S. Associations of Weather Conditions with Adolescents' Daily Physical Activity, Sedentary Time, and Sleep Duration. <https://doi.org/10.1139/apnm-2019-0309> 2019, 44, 1339–1344, doi:10.1139/APNM-2019-0309.
16. Beets, M.W.; Bornstein, D.; Beighle, A.; Cardinal, B.J.; Morgan, C.F. Pedometer-Measured Physical Activity Patterns of Youth: A 13-Country Review. *Am J Prev Med* 2010, 38, 208–216, doi:10.1016/J.AMEPRE.2009.09.045.
17. Tudor-Locke, C.; Craig, C.L.; Beets, M.W.; Belton, S.; Cardon, G.M.; Duncan, S.; Hatano, Y.; Lubans, D.R.; Olds, T.S.; Raustorp, A.; et al. How Many Steps/Day Are Enough? For Children and Adolescents. *Int J Behav Nutr Phys Act* 2011, 8, doi:10.1186/1479-5868-8-78.
18. Duncan, J.S.; Hopkins, W.G.; Schofield, G.; Duncan, E.K. Effects of Weather on Pedometer-Determined Physical Activity in Children. *Med Sci Sports Exerc* 2008, 40, 1432–1438, doi:10.1249/MSS.0B013E31816E2B28.
19. Rahman, S.; Maximova, K.; Carson, V.; Jhangri, G.S.; Veugelers, P.J. Stay in or Play out? The Influence of Weather Conditions on Physical Activity of Grade 5 Children in Canada. *Canadian Journal of Public Health* 2019, 110, 169–177, doi:10.17269/S41997-019-00176-6/TABLES/3.
20. Von Elm, E.; Altman, D.G.; Egger, M.; Pocock, S.J.; Gøtzsche, P.C.; Vandenbroucke, J.P. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: Guidelines for Reporting Observational Studies. *PLoS Med* 2007, 4, 1623–1627, doi:10.1371/JOURNAL.PMED.0040296.

21. De Castro Muñoz De Lucas, M. Clima y Cambio Climático En Castilla-La Mancha. In Impactos del Cambio Climático en Castilla-La Mancha; Instituto de Ciencias Ambientales de Castilla-La Mancha, Ed.; Toledo.
22. Casado-Robles, C.; Mayorga-Vega, D.; Guijarro-Romero, S.; Viciano, J. Validity of the Xiaomi Mi Band 2, 3, 4 and 5 Wristbands for Assessing Physical Activity in 12-to-18-Year-Old Adolescents under Unstructured Free-Living Conditions. *Fit-Person Study. J Sports Sci Med* 2023, 22, 196, doi:10.52082/JSSM.2023.196.
23. Almeida, L.; Barros, N.; Ferrari-Piloni, C.; Torres, É.M.; Estrela, C.; Valladares-Neto, J. Effect Size: A Statistical Basis for Clinical Practice. *Revista Odonto Ciencia* 2019, 33, 84–90, doi:10.15448/1980-6523.2018.1.29437.
24. Sterne, J.A.C.; White, I.R.; Carlin, J.B.; Spratt, M.; Royston, P.; Kenward, M.G.; Wood, A.M.; Carpenter, J.R. Multiple Imputation for Missing Data in Epidemiological and Clinical Research: Potential and Pitfalls. *BMJ* 2009, 338, 157–160, doi:10.1136/BMJ.B2393.
25. Weaver, R.G.; Hensing, C.; Armstrong, B.; Adams, E.L.; Beets, M. Seasonal Shifts in Children's Sedentary Behaviors, Physical Activity, and Sleep: A Systematic Review and Meta-Analysis. *Pediatr Clin North Am* 2022, 69, 671–693, doi:10.1016/J.PCL.2022.04.005.
26. Carson, V.; Spence, J.C. Seasonal Variation in Physical Activity Among Children and Adolescents: A Review. *Pediatr Exerc Sci* 2010, 22, 81–92, doi:10.1123/PES.22.1.81.
27. Lewis, L.K.; Maher, C.; Belanger, K.; Tremblay, M.; Chaput, J.P.; Olds, T. At the Mercy of the Gods: Associations Between Weather, Physical Activity, and Sedentary Time in Children. *Pediatr Exerc Sci* 2016, 28, 152–163, doi:10.1123/PES.2015-0076.
28. Gray, C.; Gibbons, R.; Larouche, R.; Sandseter, E.B.H.; Bienenstock, A.; Brussoni, M.; Chabot, G.; Herrington, S.; Janssen, I.; Pickett, W.; et al. What Is the Relationship between Outdoor Time and Physical Activity, Sedentary Behaviour, and Physical Fitness in Children? A Systematic Review. *International Journal of Environmental Research and Public Health* 2015, Vol. 12, Pages 6455-6474 2015, 12, 6455–6474, doi:10.3390/IJERPH120606455.
29. Rowlands, A. V.; Hughes, D.R. Variability of Physical Activity Patterns by Type of Day and Season in 8-10-Year-Old Boys. *Res Q Exerc Sport* 2006, 77, 391–395, doi:10.1080/02701367.2006.10599373.
30. Ren, H.; Zhou, Z.; Liu, W.K.; Wang, X.; Yin, Z. Excessive Homework, Inadequate Sleep, Physical Inactivity and Screen Viewing Time Are Major Contributors to High Paediatric Obesity. *Acta Paediatr* 2017, 106, 120–127, doi:10.1111/APA.13640.

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