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Influence of weather variables on physical activity assessed by accelerometry across age and gender groups

Influência das variáveis do clima na atividade física avaliada por acelerometria em homens e mulheres de diferentes faixas etárias

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ABSTRACT

The purpose of this research was to study the effects of weather on physical activity and compliance to minimum physical activity recommendations. Participants included 257 women and 178 men. Time spent in physical activity, average daily steps, and weather variables were gathered and analysed to explore the influence of weather on PA and compliance with the PA recommendations. In result, environmental factors may have a weak influence in an individual will to engage in PA, and individuals highly committed to an active lifestyle (based on the number of steps taken per day) did not seem to be influenced by any of the weather variables. To conclude, considering the known barriers to an active lifestyle, this information is markedly important since engaging in physical activity on a day-to-day basis may be of extreme relevance to the maintenance of a healthy status, especially in the elderly.

KEYWORDS

Accelerometry; Physical activity; Weather; Adults.

RESUMO

O objetivo deste estudo foi analisar os efeitos do clima na atividade física e no cumprimento das recomendações para a atividade física, numa amostra constituída por 257 mulheres e 178 homens. O tempo despendido em atividade física, média de passos diários, e as variáveis do clima, foram recolhidas e analisadas no sentido de explorar a influência do clima na atividade física e no cumprimento das recomendações para a atividade física. Os resultados indicam que os fatores do clima têm uma fraca influência na vontade de um indivíduo se envolver na atividade física, e que indivíduos altamente comprometidos com um estilo de vida ativo (baseado no número de passos dados por dia) não parecem ser influenciados por qualquer das variáveis do clima. Considerando o conhecimento disponível associado às barreiras à manutenção de um estilo de vida ativo, esta informação parece ser relevante em trabalhos de intervenção, já que o envolvimento na atividade física diariamente é importante para a manutenção de um bom estado de saúde, especialmente nos idosos.

PALAVRAS-CHAVE

Acelerometria; Atividade física; Clima; Adultos.

INTRODUCTION

Sedentary behaviour is related to several chronic diseases and is among the top three modifiable risk factors for premature mortality, cardiovascular disease and several other chronic diseases, including diabetes, cancer, obesity, hypertension, bone and joint diseases and depression [1, 2]. Despite these risks, a high percentage of people are inactive. To define more adequate strategies to promote physical activity (PA), several studies on the barriers that prevent an active lifestyle have been performed [3, 4].

Studies show that lower levels of PA, and consequently poor health behaviours, are associated with the following factors: marital status, obesity, smoking, time constraints, past exercise habits, and environmental variables [4]. According to a meta-analysis by Humpel et al. (2002a), environmental factors, such as accessibility to facilities, opportunities for activity, weather, safety, and aesthetic attributes, affect health behaviours. Research on environmental factors affecting PA has focused on the association between PA and either the built environment [5] or the natural environment [6].

When considering natural environmental factors (including the terrain, vegetation and weather) that influence active behaviours, other questions have been raised [5-7]. In contrast to built environmental factors, factors associated with the natural environment, such as the weather, besides not being possible to control, may also play an important role in influencing people's engagement in PA on a day-to-day basis because these factors may change daily.

According to Humpel et al. [8], weather variables are a barrier to PA. Studies based on self-reporting and objective measures show that people who are committed to exercise or engage in PA for pleasure are less likely to alter their PA behaviours due to adverse weather conditions [3, 7, 9].

A review by Chan et al. [10] focused on the effects of weather conditions on PA and categorised studies into two groups: studies that used season as a weather indicator and studies that objectively measured climatological conditions. Of the 24 studies reviewed, 16 used season as a climate indicator, and the other 8 examined the effects of weather (isolated weather indicators) on PA.

In analysing the methods used in the eight studies in Chan's review that examined the effects of weather (isolated weather indicators) on PA, we found that there´s a big inconsistency in methods used by researchers, and that only one study measured PA by means of accelerometry involving adult samples in the United States [11].

The purpose of this research was to study the effects of weather on PA. More specifically, we aimed to analyse which weather variables most influence total PA, MVPA, and steps taken per day (measured by an accelerometer). Moreover, we aimed to analyse these influences on compliance to the minimum PA recommendations.

METHODS

Participants

Eligible participants were male and female adults over 20 years of age who resided within the geographic area defined for the study (Municipality of Vila Real, located in north Portugal), were willing to participate, and who did not suffer from any motor incapacity that could limit their participation.

Participants were recruited by word of mouth. To better characterise the population within the defined region, individuals were recruited regardless of whether they were involved in PA or an exercise programme and independently of their marital or socio-economic status.

Of the 627 subjects initially recruited and evaluated, 190 did not wear the accelerometer for at least four days or had battery failure or equipment malfunction. Therefore, the final sample included 435 participants.

The participants included 257 women (aged from 20 years to 96 years, BMI 26.75 $kg \cdot m^{-2} \pm 4.57$ $kg \cdot m^{-2}$) and 178 men (aged from 20 years to 88 years, BMI 26.81 $kg \cdot m^{-2} \pm 3.51$ $kg \cdot m^{-2}$).

To compare data, the participants were classified into three age categories (20–39 years, 40–59 years and ≥ 60 years), according to the stratification data from other studies [12].

Procedures

The study has been approved by the research ethics committee of the host university were the research took place. The study design and experimental procedures were explained to potential participants and after recruitment, participants willing to participate signed an informed consent and completed a socio-demographic questionnaire in addition to being assessed for height and weight.

Each individual was monitored for four to seven consecutive days (including weekdays and weekend days), according to studies reporting that at least three to five days of monitoring should be considered in adults [13].

Subjects were fitted with a belt with an attached accelerometer held closely around their waist and were instructed to wear the accelerometer directly over their iliac crest during all waking hours for four to seven consecutive days, except when showering, bathing, or swimming. Participants were asked to put on the accelerometer first thing in the morning, remove it immediately before going to bed at night, and record the times in a brief log. Any other activity that was performed while not using the accelerometer (e.g., swimming or showering) had to be marked in the log to account for the activity in the data analysis as non-wear time (as opposed to a malfunction in the device). At the end of the collection days, individuals delivered the accelerometer and log to the staff.

Data collection began in September 2008 and ended in April 2010. August was not included in the evaluation because most participants were on summer holiday.

Accelerometer, data reduction and outcome measures

The ActiGraph model (ActiGraph GT1M, ActiGraph, Pensacola, Fla.) was used to assess PA objectively. Devices were calibrated according to the manufacturer's instructions. The validity and reliability of accelerometers within and across monitors have been previously tested [14].

Freedson cut-off points [15], adapted by Mathews and colleagues, were used to evaluate the time spent in different-intensity activities of those under 60 years old [16]. PA intensity categories were defined as the following: inactive (from 0 $ct \cdot min^{-1}$ to 500 $ct \cdot min^{-1}$), light (500 $ct \cdot min^{-1}$ to 1,952 $ct \cdot min^{-1}$), and moderate to vigorous (above 1,952 $ct \cdot min^{-1}$). These cut-off points were derived from an adult population and were calibrated for walking, the most frequently performed activity.

Because there are no validated cut-off points for elderly individuals and the use of a single cut-off point for all adults may underestimate moderate PA intensity in the elderly, the cut-off points from Davis [17] were used to analyse data from subjects above 60 years old. For this population, the defined categories included sedentary activity (less than 200 ct·min^{-1}), light activity (ranging from 200 to 1,999 ct·min^{-1}), and moderate-to-vigorous physical activity (above 1,999 ct·min^{-1}). These cut-off points were chosen because they have been used in other studies with similar samples [18, 19].

Intensity categories that corresponded to the same metabolic equivalents as defined for adults and the elderly were given different designations by the researchers (e.g., 'inactive' for adults and 'sedentary' for the elderly). To standardise the terminology and facilitate data presentation, interpretation and comparisons, the categories sedentary activity, light activity, and moderate-to-vigorous PA (MVPA) were used.

Valid data used for analysis consisted of days when a minimum of 10 h of data were collected per day for at least four days. We used 1-min cycles, and 60 min or more of consecutive zero counts were considered missing data or non-wear time and were eliminated from the study [20]. Accelerometer malfunction was identified as having counts greater than 18,000 ct·min^{-1}. Participants' logs were checked for non-wear time and matched against the accelerometer data. The pedometer function was pre-set to record steps per day (steps·day^{-1}).

Public recommendations have noted the importance of environmental factors as potential barriers to regular participation in healthy levels of PA. Adherence to recommendations for PA, suggest accumulating a minimum of 30 min of MVPA on most days or, preferably, every day for health benefits [21]. These PA recommendations were examined by accumulation in single minutes or in bouts of more than 10 minutes above the MVPA threshold. Because other PA recommendations are relevant because of its association to an active lifestyle, compliance to the goal of 10,000 steps per day was also analysed.

We estimated our outcome variables according to the following:

- Daily time spent in MVPA (min·day^{-1});
- Daily average intensity of total PA (ct·min^{-1}); and
- Steps per day (steps·day^{-1}).
- Data were reduced using MAHUffe software, available online (www.mrc-epid.cam.ac.uk/).

Objective measures of PA were combined with objective measures of weather indicators to accurately correlate the two. Results from daily weather variables (temperature, precipitation, percentage of relative humidity, and sunlight hours) were considered for each participant on the days that accelerometer data were collected. Data from weather variables were provided by the Institute of Meteorology of Portugal (I.M., I.P.).

Statistical analysis was conducted using PASW Statistics version 18 (SPSS Inc, USA) and Excel 2007 (Microsoft Corporation). Descriptive statistics are expressed as absolute and relative frequencies, means and standard deviations.

Multiple linear regression was used to estimate MVPA (ct·min-^{1}), daily mean ct·min^{-1} (ct·min-^{1}), and steps per day from weather variables using a stepwise method. As further ahead is noticed, with the utilization of stepwise

method, some models, only consider one variable, besides the constant, as the explanation factor. These results in different types of regression: simple an multiple regression, to explain the behavior of the dependent variable. Weather variables comprised the following: mean daily air temperature (°C), mean relative humidity (%), total precipitation (mm) and total sunlight (h).

The following assumptions of the linear regression analyses were checked: a) outliers; b) independence; c) normality; and d) the constant variance. All the assumptions were met. Outliers were tested using the casewise diagnostic with the value of three standard deviations. Independence of data points was checked using the Durbin-Watson Estimate. Normality assumptions were checked by analysing the histograms and the normal probability plots which indicated that the normal distribution of the variables was satisfied. Finally, the constant variance was checked by examining the scatter plot of the standardized residual versus the standardized predicted value, which revealed no clear pattern, from which we concluded that the variance was constant [22].

Statistical significance level was set at $p \leq 0.05$.

RESULTS

The studied population consisted of 435 subjects (59% women). Their characteristics are summarised in Table 1. The final sample included 69.6% of the eligible sample of 627 participants.

TABLE 1 – Descriptive characteristics of the subjects in total sorted by gender

	All (N=435) Mean ± SD	Women (N=257) Mean ± SD	Men (N=178) Mean ± SD
Age (yr)	54.99 ± 20.10	58.99 ± 18.93	49.22 ± 20.39
Weight (kg)	69.95 ± 13.31	64.42 ± 11.22	77.93 ± 11.99
Height (cm)	161.43 ± 10.33	155.25 ± 6.96	170.33 ± 7.51
BMI (kg/m²)	26.77 ± 4.16	26.75 ± 4.57	26.81 ± 3.51

The number of valid days the accelerometer was worn ranged from 4 to 7 days for the whole sample, and the time the device was worn ranged from 10.22 to 18.48 hours per day. Descriptive characteristics of the weather variables corresponding to the days of PA data collection are summarised in Table 2, and general results are summarised in Table 3.

TABLE 2 – Descriptive characteristics of weather variables [temperature (ºC), relative humidity (%), precipitation (mm) and sunlight (h)] during the days of PA data collection.

	Temperature (ºC)	Relative Humidity (%)	Precipitation (mm)	Sunlight (h)
Mean	12.7	64.5	2.48	6.92
SD	4.82	13.38	3.97	3.27
minimum	2.02	30.66	00.00	0.27
maximum	24.12	92.50	16.61	13.40

The variation in the total volume of PA in women aged 40–59 years was associated to relative humidity (4.4%, p=0.032), and the proportion of the variation in the number of steps taken daily by these women explained by the number of hours of sunlight was approximately 4.6% (p=0.029).

TABLE 3 – Estimation of MVPA (ct·min-1), daily mean ct·min-1 (ct·min-1), and steps per day from weather variables - mean daily air temperature (°C), mean relative humidity (%), total precipitation (mm) and total sunlight (h).

	Unstandardized Coefficients		T	
	B	Std. Error	Test	Sig
MVPA (ct·min-1)				
Women (>60); n=127				
Constant	26.33	2.729	9.649	0.000
Precipitation (mm)	-1.045	0.476	-2.193	0.030
Men (20-39); n=72				
Constant	-147.463	47.785	-3.086	0.003
Sunlight (h)	10.184	2.310	4.408	0.000
Relative Humidity (%)	1.911	0.499	3.828	0.000
Men (>60); n=62				
Constant	6.186	11.138	0.555	0.581
Temperature (ºC)	2.383	0.786	3.029	0.004
Compliers to 30-min MVPA				
Women (20-39); n=47				
Constant	58.505	5.904	9.910	0.000
Precipitation (mm)	3.215	1.568	2.050	0.049
Compliers to 30-min MVPA				
Women (40-59); n=83				
Constant	85.832	9.624	9.918	0.000
Temperature (ºC)	-1.823	0.752	-2.425	0.019
Compliers to 30-min MVPA				
Men (20-39); n=72				
Constant	-137.681	52.628	-2.616	0.012
Sunlight (h)	9.893	2.436	4.062	0.000
Relative Humidity (%)	1.921	0.558	3.444	0.001
Compliers to 30-min MVPA				
Men (40-59); n=44				
Constant	66.416	5.733	11.584	0.000
Precipitation (mm)	-3.627	1.540	-2.355	0.026
Compliers to 30-min MVPA				
Men (>60); n=62				
Constant	44.835	15.406	2.910	0.008
Temperature (ºC)	2.201	0.959	2.295	0.032
Daily average physical activity (ct·min-1)				
Women (40-59); n=83				
Constant	204.915	86.733	2.363	0.021
Relative Humidity (%)	2.897	1.326	2.185	0.032
Women (>60); n=127				
Constant	248.551	17.710	14.034	0.000
Precipitation (mm)	-6.667	3.091	-2.157	0.033
Men (>60); n=62				
Constant	143.000	65.561	2.181	0.033
Temperature (ºC)	12.373	4.629	2.673	0.010
Steps per day				
Women (40-59); 44				
Constant	11.237.188	775.066	14.498	0.000
Sunlight (h)	-245.051	110.121	-2.225	0.029
Men (>60); n=62				
Constant	3.202.423	1.435.369	2.231	0.029
Temperature (ºC)	307.989	101.351	3.039	0.004

The total amount of PA and MVPA in women above 60 years old were influenced negatively by precipitation, with effect magnitudes of approximately 2.8% (p=0.030) and 2.9% (p=0.033), respectively.

For men above 60 years old, temperature explained 9.2% of the variation in total volume of PA (p=0.01), 11.8% of the fluctuation in MVPA (p=0.00), and 11.9% of the number of steps taken per day (p=0.000). As the temperature increased by 1°C, older men increased the total volume of PA by 12 ct·min^{-1}, spent 2 min·day^{-1} more in MVPA, and took 307 more steps per day.

On the other hand, for all other gender/age groups, weather indicators did not explain the variations in PA.

Analysis of compliance with the recommendation of at least 30 min above MVPA showed that variation in MVPA in women aged 20 to 39 years was influenced by precipitation (p=0.049), explaining 8.8% of this variation. An increase in precipitation induced a mean increase in MVPA of 3 min·day^{-1}.

Fluctuations in PA in complying women 40–59 years old were explained by temperature (8.3%, p=0.019). Increases in temperature of 1°C reflected a mean decrease in MVPA of approximately 2 min·day^{-1}.

Among men aged 20–39 years who complied with the referred target PA, fluctuations in MVPA were explained in 2.1% by sunlight and relative humidity (p=0.00 and p=0.001, respectively). Increases in sunlight of 1 h and in relative humidity of 1% induced mean increases in MVPA of 9.8 and 1.9 min·day^{-1}, respectively.

Precipitation explained 13.2% of the variation in MVPA in complying men 40 to 59 years old (p=0.026). As precipitation increased by 1 mm, MVPA decreased approximately 4 min·day^{-1}. Finally, complying men above 60 years of age were affected by temperature (p=0.032), which explained approximately 15.6% of the variation in MVPA.

Neither of the gender or age groups that comply to the recommendation of 10,000 steps per day was influenced by weather variables.

DISCUSSION

This study aimed to examine the effects of weather variables on total PA, MVPA, and steps taken per day in adults and elderly individuals. Moreover, we analysed these influences on those who comply to the recommended PA. To our knowledge, only one study in the U.S. has measured PA by means of accelerometry and has isolated weather variables to simultaneously analyse the effects of weather in PA in adults and elderly individuals [11].

Our results show that variations in PA level and in the number of steps taken per day in a Portuguese population were influenced by different weather factors, but the magnitude of these effects varied. Previous studies involving elderly adults based on pedometers found similar correlations between weather variables and PA [23].

Surprisingly, sunlight had a small but negative influence on the number of steps taken daily by women 40–59 years old. These results indicate that an increase in sunlight led to a decrease in the number of steps taken per day. Previous studies referred to day length and not sunlight, and research using objective measures similar to the ones used in this study have not yet been reported for normal adults and elderly individuals or adults stratified by age and gender groups.

The total amount of PA and MVPA in elderly women were negatively influenced by precipitation. These findings are in line with previous research on the relationship between older women's participation in an exercise class and environmental variables, which found that any amount of precipitation induced a 25–40% decrease in class attendance [24]. Furthermore, a study consisting of 41 older Japanese people (above 70 years) revealed that the number of steps taken per day decreased with increasing precipitation [23], as well as for another study [7]. We could not confirm that precipitation was the most influential on PA of all the weather variables, as suggested previously [10], because different influences were found for each age and gender group.

In older men, temperature was the weather variable that best explained the variation in total PA, MVPA and the number of steps taken per day. As temperature increased by 1°C, older men increased their total PA by 12 ct·min^{-1}, spent 2 min more in MVPA, and took 307 more steps per day. The results for older men confirm data from previous studies that used self-reporting and objective measures [11, 23, 25] and that found a curvilinear relationship between the number of steps taken and temperature in older adults. One of those studies showed that PA during the summer peaked at temperatures of 20°C and declined as temperatures continue to rise beyond this value, until it reached 30°C. At that point, they observed a significant drop in PA. These results referred to PA and weather variables measured for a period of 7 hours, which corresponded to daytime (0700 to 1900 hours). However, the activities performed by elderly individuals may have been taking place during the early hours of the morning or late hours of the afternoon to avoid extreme temperatures and were thus not accounted for in their results. Studies have also suggested that since thermoregulatory capacity decreases with age [26, 27], younger adults less were less affected by temperature than elderly adults. This assumption may explain the differences in results found in this variable, for these age groups.

Self-reporting studies show that individuals committed to exercise or that engage in PA for pleasure are less likely to refer to weather as a barrier or to alter their behaviours towards PA due to adverse weather conditions [8, 9]. Our analysis of those who comply with the recommendation of attaining at least 30 min of MVPA showed that variations in MVPA in women 20 to 39 years old were positively influenced by precipitation. These results may seem surprising; however, previous studies based on self-reporting have also found that days of uninterrupted precipitation have positive effects on PA among men [11], probably due to a peak in household activities. In another perspective, women of this age may also be involved in organized activities performed in a more controlled environment, as suggested previously for younger groups of age [28]. The fluctuations in MVPA in complying women 40–59 years old were weakly explained by temperature and in men of the same age by precipitation. Complying men above 60 years old were affected by temperature. These results may indicate that those who comply with this PA recommendation are influenced by weather variables, which contradicts previous results. However this recommendation has weaknesses because it considers the accumulation of 30 individual min above the MVPA threshold and not only those performed in bouts of 10 or more min above this threshold, as advised in the newest recommendations of PA, but "harder" to maintain.

Regarding the individuals who complied with the PA recommendation for 10,000 steps per day, none of these individuals, regardless of their age or gender groups, was observed to be influenced by weather variables. The achievement of this recommendation is associated to an active lifestyle [29], and therefore, these results agree with previous findings that suggest that individuals highly engaged in PA are less likely to refer to weather as a barrier or to alter their behaviours towards PA in adverse weather conditions [3]. Previous studies have also revealed that despite the rain patterns, a small amount of walking still takes place [7]. This argument could explain our results if we consider that individuals attaining this target PA are committed to an active lifestyle. If this were true, then regardless of the weather conditions, they would continue to engage in PA. In addition, observational studies on the direct effects of weather in real-time reveal that regular joggers and walkers are not influenced by any of the weather variables [30].

In our study, when an objective assessment of PA was made, objective measures of weather indicators were also taken. Thus, a more accurate correlation between PA and weather elements was established. However, it was impossible to analyse hour-to-hour data because data from I.M., Portugal, referred only to daily measures (over 24 h) and hourly data were not available. The data presented in this study corresponded to daily isolated weather variables associated with day-to-day measured PA and not to a season, which would include several weather variables, associated with PA. Therefore, limitations associated to interaction between weather factors should be considered in this investigation.

Our participants were recruited bearing in mind the need to have individuals both involved and not involved in PA and/or exercise programs to avoid the bias associated to perception (or not) of the climate as a barrier to physical activity, and that has occurred in other studies whose sample was recruited from intervention programs and therefore may not be representative of the whole population,.

The data of weather variables are restricted to the weather characteristics in the specific region where the data collection took place, which may have limited the amplitude of each variable and may not have accounted for all weather ranges and combinations from other specific locations. Also, longer monitoring of the individuals would yield more powerful results. Finally, the small sample size used in this investigation must also be acknowledged. For these reasons, the results from this investigation may not be generalised to other populations.

Future investigations should provide data from gender and age groups in large samples, explore comparisons between rural and urban settings, or study differences in demographic characteristics of the sample should be encouraged.

Our results indicate that environmental factors may have a weak influence in an individual's will to engage in PA, and that individuals highly committed to an active lifestyle (based on the number of steps taken per day) don´t seem to be influenced by any of the weather indicators. However, further analysis of the influences of weather variables on individuals involved or not in exercise or PA interventions would help clarify whether individuals who are firmly committed to PA are less influenced by weather factors and if this information should be taken into consideration when defining interventions and health promotion efforts designed to increase PA levels.

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