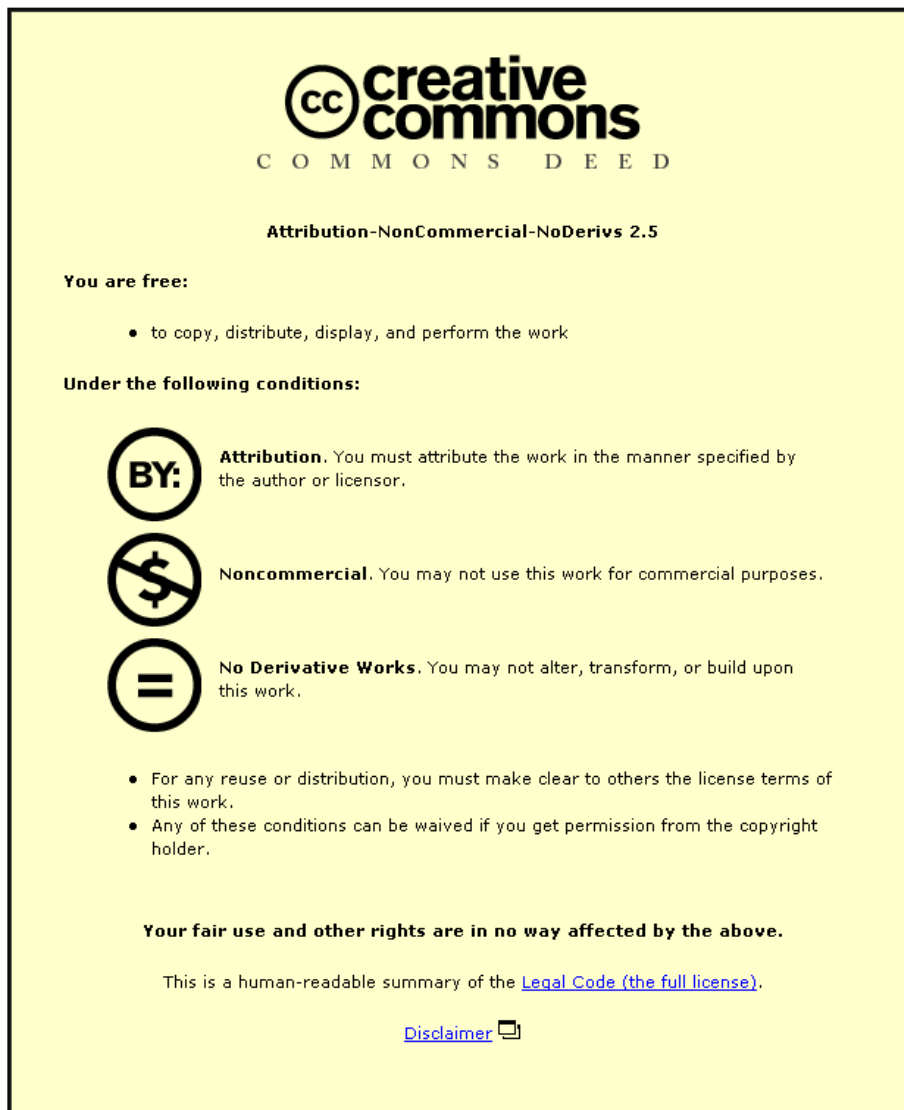


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
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
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UK adults exhibit higher step counts in summer compared to winter months

Running Head: Seasonal variation in adult step counts

Keywords: Ambulatory activity, pedometer, seasonal, adults

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Abstract

Background: Seasonal differences in step counts have been observed in a limited number of studies conducted on US adults. Due to the diverse global climate, assessment and interpretation of seasonal patterns in ambulatory activity may vary between countries, and regionally specific studies are necessary to understand global patterns. Currently, no studies have assessed whether a seasonal trend is present when ambulatory activity is measured objectively in adults living in the UK.

Aim: To investigate whether pedometer-determined step counts of adults living in the UK vary between summer and winter.

Subjects and methods: Ninety-six adults (52% male, age = 41.0 ± 12.3 years, BMI = 26.1 ± 5.1 kg/m²) completed a within-subject bi-seasonal pedometer study. All participants completed two four-week monitoring periods; one during the summer and one the following winter. The same Yamax SW-200 pedometer was worn throughout waking hours during both seasons, and daily step counts were recorded in an activity log. Intra-individual seasonal changes in mean daily steps were analysed using a paired samples *t*-test.

Results: Summer mean daily step counts (10417 ± 3055 steps/day) were significantly higher than those reported during the winter (9132 ± 2841 steps/day) ($p < 0.001$). A follow-up study conducted the subsequent summer in a sub-sample ($n = 28$) reinforced this trend. Summer step counts were significantly higher than winter step counts on all days of the week ($p \leq 0.001$). A significant day of the week effect was present in both seasons, with step counts reported on a Sunday being on average 1,500 steps/day lower than those reported Monday through to Saturday.

Conclusion: Step counts in the sample of UK adults surveyed decreased significantly in the winter compared to the summer, suggesting future pedometer surveillance studies should capture step counts throughout the year for a non-biased reflection of habitual ambulatory

activity. Public health initiatives should target these seasonal differences and opportunities should be provided which encourage individuals to increase their activity levels during the colder, darker months of the year.

Introduction

Obesity levels in the UK are rising, approximately 24% of male and female adults living in the UK were classified as obese in 2004 (characterised by a body mass index [BMI] ≥ 30 kg/m² (WHO 2000)), compared with 14% of males and 17% of females classified as obese in 1994 (Department of Health 2005). This increasing trend is allied with a heavy financial burden on the health service, which is estimated to cost approximately £7 billion per annum (House of Commons Health Committee 2004), due to the augmented disease risk associated with excess body fat. Numerous chronic diseases including coronary heart disease, type 2 diabetes, hypertension and certain cancers can be influenced by an obese state (Haslam and James 2005). Physical inactivity is widely documented as a major risk factor for obesity (Hill and Melanson 1999), and despite attempts to disseminate this knowledge to the general population, it is predicted that about two-thirds of UK males and three-quarters of UK females do not attain physical activity levels required for health benefits (undertaking a minimum of 30 minutes of at least moderate intensity activity, at least five times per week) (Department of Health 2005). It is therefore essential to understand the activity patterns of these at risk individuals, in order to appropriately target public health initiatives.

Physical activity levels tend to fluctuate according to season, being characteristically highest during the summer and lowest during the winter. This seasonal pattern has been well defined in large scale self-report studies, which have examined changes in leisure-time, occupational and household activity, in the USA (Dannenberg et al. 1989; CDC 1997; Matthews et al. 2001; Pivarnik et al. 2003) and UK (Uitenbroek 1993). Self-report measures of physical activity can however lack validity in that individuals often exhibit an inability to accurately self-assess low intensity activities, such as walking behaviour (Sallis and Saelens 2000). This may have implications for the use of self-report measures in sedentary societies. Walking is

reportedly the most prevalent form of physical activity in both US (Simpson et al. 2003) and UK adults (Chief Medical Officer 2004). However, walking is commonly underestimated through questionnaires (Ainsworth et al. 1993; Richardson et al. 1994; Bassett et al. 2000). By not capturing walking, or ambulatory, behaviour adequately, self-report studies may lack the sensitivity needed to detect the actual seasonal physical activity experience of many individuals.

Pedometers are rapidly gaining popularity in the research domain. The combination of their low cost, small size, simplicity and unobtrusive nature make them practical tools for objectively monitoring ambulatory activity in the free-living environment. Although accurate in measuring steps (Bassett et al. 1996), pedometers are not designed to capture short-term patterns in activity (<24 hours), intensity, or type of exercise (Tudor-Locke et al. 2002). The standardised steps per day unit of measurement enjoys universal interpretation, facilitating reliable cross-population comparisons. This type of comparison is often limited when using subjective measures (Lamb and Brodie 1990). However, despite the potential for pedometers to measure activity, to date there is limited data available describing the seasonal patterns in ambulatory activity of healthy free-living adults.

Previous studies that have objectively assessed seasonal variability in ambulatory activity have been limited by either gender and duration (Lee et al. 1987), study aim (Chan et al. 2006) or sample size (Tudor-Locke et al. 2004a). Lee et al. (1987) compared summer and winter pedometer data collected in Kentucky, from 130 females aged 51 to 86 years, over two seasonally separate seven day monitoring frames. A significant summer to winter reduction in steps was reported in the form of distance walked. Chan et al. (2006) conducted a pedometer-based intervention with the aim to raise activity levels in Canadian adults ($n =$

203). Step count data were collected from two groups of participants, data from one group were collected between the months of March and July, and data from the second group were collected between December and April. Although a seasonal change in step counts was observed, the study aim was to increase walking activity and therefore it is unlikely that habitual levels were captured. Tudor-Locke et al. (2004a) assessed daily step counts reported over a continuous 365 day period in 23 US male and female adults. Although this preliminary study indicated a winter reduction in steps, the authors acknowledge the need for research to be conducted in a larger sample to confirm their findings.

All research to date investigating seasonal changes in ambulatory activity (outlined above) has focused exclusively on North American populations, and very little research has been published investigating pedometer-determined activity in healthy, free-living UK adults. From the research available, using pedometers in UK adults, Clemes et al. (2007; 2008a) reported that mean daily step counts, measured in normal-weight, overweight and obese UK adults were higher, by approximately 3000 steps/day, than those observed in US adults. This suggests that there are potentially differences in activity levels between UK and US adults. No research has yet investigated seasonal changes in ambulatory activity of UK adults.

Seasonal changes in physical activity are thought to be mediated through changes in the environment, with ambient temperature, daylight hours and precipitation considered most influential (CDC 1997; Merrill et al. 2005). Due to the diverse global climate, assessment and interpretation of seasonal patterns in ambulatory activity may vary between countries, and regionally specific studies are necessary to understand global patterns. For example, the climate in the UK is very different to the climate in the US. Climate data collected over a 30 year period in the UK show that minimum and maximum temperatures during summer and

winter range between 10.3°C to 19.9°C (summer) and 1.0°C to 6.7°C (winter), respectively (Met Office, 2006). In contrast, climate data collected over the same time period from the state of South Carolina (one of the two locations used in the study by Tudor-Locke et al. (2004a)) show minimum and maximum temperatures between 21.8°C to 31.6°C and 4.1°C to 15.6°C in summer and winter respectively (Met Office, 2006).

Given the number of sedentary adults and the rising problem of obesity in the UK, it is important to understand seasonal physical activity patterns of UK adults in order to develop appropriate public health initiatives. The aim of the current study therefore was to measure the seasonal variation in ambulatory activity of free-living UK adults, by comparing pedometer determined activity levels, collected over the summer and winter months.

Methods

Experimental design

A within-subjects repeated measures design was employed, which consisted of two methodologically identical data collection periods. The first period of data collection took place during the summer of 2005, between the 21st June and the 22nd September. The data collected during this time period has been reported elsewhere (Clemes et al. 2007). Participants were recalled and requested to repeat the ‘summer’ study during the following winter. The winter data collection period took place between the 20th January 2006 and 21st March 2006. This paper details exclusively those participants who completed both the summer and winter monitoring periods ($n = 96$).

Participants

Participants were recruited during the summer of 2005 from two different counties in the United Kingdom - Leicestershire ($n = 70$) and Cornwall ($n = 52$) - through advertisements placed in local media. An equal number of male and female adult participants were recruited using a quota-based sampling frame that was developed to achieve an even spread of individuals across the age range of 18 to 65 years. The sampling frame also ensured that, at the study outset, an equal number of participants were classified as either normal weight ($BMI < 25$) or overweight ($BMI \geq 25$), to reflect the 2004 prevalence of overweight in UK adults (Department of Health 2005).

Upon completion of the summer monitoring frame participants were asked if they would be willing to repeat the procedure the following winter. Eight participants indicated that they would not be available during the designated winter testing period, the remaining 114 participants consented and were re-approached the following autumn via email or telephone. Winter study exclusion criteria encompassed any non-seasonal lifestyle change made since completion of the summer study which may affect physical activity levels. Participants were screened for Seasonal Affective Disorder (Partonen and Lonnqvist 1998). Ninety-nine participants started the winter monitoring period, 6 participants did not respond to the follow-up invitation made in the autumn and a further 9 participants met winter exclusion criteria. Reasons for exclusion were; moved away from the monitoring area ($n = 6$), divorced since the summer monitoring frame resulting in changes to daily routine, not associated with the season ($n = 1$), had a demobilising injury ($n = 1$), changed occupation ($n = 1$).

Responses on a health screen questionnaire completed prior to each monitoring period confirmed that participants were all in good general health and none had any physical illness

or disability that might affect their normal daily routine. The study received ethical approval from the Loughborough University Ethical Advisory Committee. Participants received written and oral details outlining the study protocol and provided written informed consent.

Anthropometric and body composition measurements

Prior to, and following the summer and winter monitoring periods, body weight and percentage body fat were measured in the laboratory using a Tanita Segmental Body Composition Analyser BC-418MA (Tanita UK Ltd, Middlesex), that measures body composition using 8-point bio-impedance analysis. This system correlates highly with the reference measure of dual-energy x-ray absorptiometry (Pietrobelli et al. 2004). Height, without shoes, was measured during the initial summer study only due to the low rate of adult height change (Sorkin et al. 1999), using a wall mounted stadiometer (Seca UK, Model: 206, Birmingham, Warwickshire, UK). BMI was calculated as weight (kg) divided by height (m) squared (kg/m^2).

Physical activity assessment

Participants were issued with the same New Lifestyles Digi-Walker SW-200 pedometer during both monitoring periods to avoid potential inter-pedometer error (for 4.8% of participants a single pedometer used cross-season was not possible due to the instrument becoming; lost ($n = 3$) or broken ($n = 2$)). However, these pedometers were replaced with the same model of pedometer.

The SW pedometer range has been shown to accurately detect steps in controlled laboratory (Le Masurier and Tudor-Locke 2003; Swartz et al. 2003; Melanson et al. 2004) and free-

living conditions (Le Masurier et al. 2004; Schneider et al. 2004) and has consequently been employed in numerous free-living activity studies (Chan et al. 2004; Tudor-Locke et al. 2004b; Hornbuckle et al. 2005). The pedometer accurately assesses walking activity of all BMI classifications (Swartz et al. 2003).

The same protocol was employed during both seasons. Participants were instructed to wear the pedometer during waking hours over a continuous four-week period, removing only while bathing, showering or swimming. An activity log was supplied in which individuals recorded their daily step count at the end of each day, along with their responses to the following two questions; 1) 'Did you go for a walk today? If yes, for how long (mins)' and, 2) 'Did you do any other physical activity today? If yes, please provide a brief description of type and duration'. Participants were asked to complete the log in the same manner during both monitoring periods and encouraged to maintain normal daily activity levels throughout. Upon completion of each monitoring period, participants completed a brief post-study questionnaire enquiring whether they had suffered from any ill health or made changes to their normal routine, diet or general activity levels during the monitoring frame. Post questionnaire data showed all participants remained in good health during both the summer and winter monitoring periods and no changes to daily routine or lifestyle were reported.

Meteorological information associated with each monitoring frame

Meteorological information was collected retrospectively, in the form of summary data, from the Met Office following data collection. Data summarising the mean, minimum and maximum temperature (°C) along with sunshine hours and rainfall volume (mm) were collected that corresponded to the summer 2005 and winter 2006 monitoring periods.

Data and statistical methods

Of the 122 participants who completed the summer monitoring frame, 79% also completed the winter monitoring frame. To ensure the participants completing both monitoring frames did not differ to those completing the summer only, the two groups were compared in terms of mean summer step counts and pre-summer study BMI using independent samples *t*-tests. The gender splits of the two groups were compared using multi-dimensional Chi-squared statistics with cross-tabulations.

The remainder of this section describes the statistical procedures employed for those participants completing both the summer and winter monitoring periods. Baseline measures of BMI and percentage body fat collected prior to the summer and winter monitoring periods, and changes in BMI and percentage body fat over the two independent four-week monitoring periods were compared using paired samples *t*-tests.

In the event that a participant forgot to record their step count value in the activity log, missing values (1%) were input using season-specific and participant-specific day of the week averages (all missing values were calculated using 3 values). This procedure to deal with missing values has been adopted elsewhere and enables more powerful statistical analyses (Rowe et al. 2004; Tudor-Locke et al. 2004a).

Season-specific mean daily step counts were calculated for each participant by averaging the complete set of 28 step count values, and summer to winter differences in mean daily step counts were analysed using a paired samples *t*-test. Effect size of steps per day was calculated to ascertain the size of the difference in step counts between seasons (Field 2005).

Mean daily step counts reported on each day of the week (Monday to Sunday) were calculated for each season by averaging the 4 step count values available for each day. A repeated measures ANOVA (with Greenhouse-Geisser correction applied) was employed to assess whether step counts varied according to the day of the week within each season. Bonferroni adjusted pairwise comparisons were performed in the event of a significant day of the week effect. Mean step counts reported on each day of the week were compared between seasons (e.g. summer mean Monday steps versus winter mean Monday steps etc.) using multiple paired samples *t*-tests, with a Bonferroni correction applied. Day-specific seasonal changes in steps were also calculated (e.g. winter mean Monday steps minus summer mean Monday steps). A repeated measures ANOVA was applied to assess whether the magnitude of seasonal change in steps varied according to the day of the week. Gender differences in overall mean daily step counts for each season were assessed using independent samples *t*-tests. The following interaction, gender-by-season-by-day of the week, was tested using a 3-way ANOVA.

In the event a participant forgot to record their activity log data (self-reported walking and other exercise), missing values (walking 1%, other data 2%) were input using season-specific and participant-specific day of the week averages (all missing values were computed from ≥ 3 values). Due to the high level of positive skew observed, time spent walking and minutes engaged in other activity, reported in the activity log, are described by the median and inter-quartile range for each season. Wilcoxon Signed Ranked Tests were used to statistically assess summer to winter differences in self-reported activity levels.

Statistical analyses were conducted using SPSS for Windows version 13.0 (SPSS Inc., Chicago, IL). Differences were considered to be statistically significant at $p \leq 0.05$ level (two-tailed).

Follow-up-study

A sub-sample of participants from the main study (28 out of 96) agreed to participate in a follow-up study conducted during the summer of 2006. The aim of this follow-up study was to confirm any seasonal changes observed during the main study and to establish any possible ordering effects that might have been influenced by pedometer reactivity. The protocol followed was exactly the same as that outlined for the previous two monitoring frames, and the same exclusion criteria applied to the winter study were also applied to this follow-up. All participants included in this sub-study remained healthy throughout according to post-study questionnaire results. Participants who completed the follow-up were compared to those who did not take part in this additional study using independent samples *t*-tests. Mean daily step counts taken by this sub-sample only, during each of the three monitoring frames, were compared using a repeated measures ANOVA and Bonferroni adjusted pairwise comparisons were performed in the event of a significant seasonal effect.

Results

Meteorological information

Meteorological data summarising the mean, minimum and maximum temperature (°C) along with sunshine hours and rainfall volume (mm) recorded by the Met Office during the two monitoring periods (Summer 2005 and Winter 2006) are shown in Table I. As anticipated, there was a marked decrease in both temperature and sunshine hours from summer to winter, whilst rainfall volume remained relatively constant between seasons.

INSERT TABLE I ABOUT HERE

Participants

Of the 99 participants who started the winter monitoring period, 3 were lost to follow-up. Ninety-six participants (78.6% of those used in the analysis of the summer monitoring period), completed both the summer and winter monitoring frames. Participants who completed only the summer section of the study did not differ significantly to those who completed both the winter and summer sections with respect to; summer mean daily step count, pre-summer study BMI or gender proportion ($p > 0.05$).

Participants who completed both summer and winter monitoring frames had a mean age of 41.0 ± 12.3 years and consisted of 46 males and 50 females. Season specific anthropometric and step count data are presented in Table II. A significant summer to winter increase in BMI and percentage body fat was observed. No significant changes in BMI and percentage body fat were observed over either of the two four-week monitoring periods (results not shown).

INSERT TABLE II ABOUT HERE

Change in mean daily steps- summer versus winter

Participants recorded 5,323 person-days of step count data out of a possible 5,376 person-days (99% compliance), meaning 1% of values had to be input based upon season-specific and participant-specific day of the week averages. Corrected (missing values replaced) mean steps/day and raw steps/day data were very similar (summer corrected = 10417 ± 3055 vs. summer raw = 10419 ± 3054 , winter corrected = 9132 ± 2840 vs. winter raw = 9132 ± 2833).

Mean winter daily steps counts were markedly lower than mean summer daily step counts ($t = -6.627$, $p < 0.001$), this significant cross-seasonal difference is evident throughout the two 28

day monitoring periods (Figure 1), with an average winter reduction in ambulatory activity of 1,286 steps per day. This resulted in an effect size of 0.56. During the summer monitoring period 50% of the sample reported a mean daily step count above the recommended 10,000 steps/day (Tudor-Locke and Bassett 2004), whilst this proportion fell to 34% during the winter monitoring period.

INSERT FIGURE 1 ABOUT HERE

Day-of-the-week variation

Table III. presents the mean daily step counts reported on each day of the week during both the summer and winter monitoring periods, along with the seasonal change in step counts occurring on each day of the week. Participants showed a consistent summer to winter reduction in mean step counts on every day of the week ($p \leq 0.001$), and the magnitude of seasonal change did not vary significantly between days of the week. Step counts reported on a Sunday were significantly lower than those reported on all other days during both seasons ($p < 0.05$, see Table. III)

INSERT TABLE III ABOUT HERE

Gender differences

There was a tendency for males to report higher mean daily step counts than their female counterparts during both seasons, (summer mean daily step counts: males = 11061 ± 3507 steps/day vs. females = 9867 ± 2479 steps/day, $t = 1.839$, $p = 0.07$, and, winter mean daily step counts: males = 9764 ± 3198 steps/day vs. females = 8550 ± 2352 steps/day, $t = 2.104$, $p = 0.038$). The magnitude of step count change between seasons was similar for both genders

and there was no statistically significant gender effect ($p = 0.868$). In addition, there was no significant gender-by-season-by-day of the week interaction (data not shown).

Seasonal variability in self-reported walking and other physical activity

One participant was excluded from this part of the analysis ($n = 95$) as activity logs were not completed in a comparative manner between both seasons; occupational walking was reported during one season only. The median (inter-quartile range) time spent engaged in self-reported walking behaviour during the summer was 13.8 (5.9, 27.3) minutes/day compared to 7.9 (0.7, 17.1) minutes/day during the winter. This resulted in a significant summer to winter reduction in self-reported walking behaviour in the range of 43% ($z = -4.377$, $p < 0.001$). Levels of self-reported 'other' physical activity were 6.4 (0, 18.8) minutes/day during the summer, reducing to 4.3 (0, 19.1) minutes/day during the winter, this reduction was not statistically significant ($z = -1.418$, $p > 0.05$).

Follow-up study

Participants who completed the follow-up study ($n = 28$) did not differ significantly from the remainder of the sample with regards to summer 2005 mean daily step counts (follow-up participants = 10466 ± 2533 steps/day vs. remaining participants = 10397 ± 3262 steps/day, $p = 0.920$) or winter mean daily step counts (follow-up participants = 9051 ± 2743 steps/day vs. remaining participants = 9165 ± 2900 steps/day, $p = 0.859$). The step count data collected in this follow-up study, conducted during the summer of 2006, confirmed the seasonal variation in step counts observed in the main study. Mean daily step counts reported during the two summer monitoring periods, in this sub-sample, did not differ significantly (summer 2005 = 10466 ± 2533 , vs. summer 2006 = 10149 ± 3019 , $p = 0.378$), whilst mean daily step counts

reported in the winter (9051 ± 2743) for this sub-sample were significantly lower than those reported during both summer monitoring periods ($p \leq 0.001$).

Discussion

The aim of this study was to determine whether step counts from a sample of adults living in the UK vary between summer and winter. There was a clear seasonal difference in ambulatory activity occurring in the sample studied, with winter levels being significantly lower than summer levels by approximately 1,300 steps/day. The seasonal change in step counts is not only statistically significant, but represents a medium to large effect size (Field 2005). The present study substantiates the preliminary work of Tudor-Locke et al (2004a) who also observed a summer to winter step count reduction in the range of 900 steps/day in a small sample of US adults ($n = 23$). The discrepancy between the two studies, in terms of the magnitude of seasonal changes in steps, is not unexpected due to the high level of inter-regional variability in habitual step counts (Sequeira et al. 1995; Tudor-Locke et al. 2004b; Dwyer et al. 2007) and further underlines the need for region-specific seasonality studies.

The change in ambulatory activity, between summer and winter, observed in this pedometer-based study is consistent with seasonal patterns reported in qualitative questionnaire-based studies, which measure a broader range of physical activities (Dannenberg et al. 1989; Uitenbroek 1993; CDC 1997; Matthews et al. 2001; Pivarnik et al. 2003). This paper objectively measured the seasonal variation in steps accumulated throughout the day, with all forms of steps contributing to the daily total. Due to the unstandardised nature of questionnaire-based studies however, no direct comparison can be made between the 12.3% seasonal change in step counts noted in the current study and the variation in walking behaviour reported subjectively. Uitenbroek (1993) only recorded walking activity lasting

more than 20 minutes, and observed a 1% seasonal change in the number of UK respondents reporting participation in walking. In contrast, when assessing seasonal changes in total minutes spent walking for pleasure, Dannenberg (1989) reported a 60% reduction from summer to winter in US adults.

Preliminary indices have recently been constructed to classify pedometer-determined physical activity levels according to the number of steps taken per day (Tudor-Locke and Bassett 2004). With respect to the mean daily step counts reported in this study, the participants could on average, be described as 'active' during the summer (10417 ± 3055 steps/day), as mean steps taken fell within the range of 10,000 and 12,500 steps/day and, 'somewhat active' during the winter (9132 ± 2841 steps/day), as mean steps taken fell within the range of 7,500 to 9,999 steps/day. In the summer monitoring period 50% of participants reported mean daily step counts above the recommended 10,000 steps/day, whilst in the winter only 34% of the sample achieved this goal. In addition to any health consequences of seasonally interrupting physical activity (discussed below), the findings of the current study also have methodological implications in that data collection restricted to one season may either overestimate or underestimate year round habitual ambulatory activity (as illustrated above). In order to obtain a non-biased reflection of general day-to-day step count levels, pedometer studies should be conducted throughout the year.

Due to the dose-response relationship between physical activity and health (Blair et al. 1992), any seasonal reduction in activity has the potential to impact negatively on health. It has been hypothesised that by stopping exercise behaviour for 'the winter period' a permanent reduction in activity may result (Uitenbroek 1993). Seasonal changes in physical activity may therefore have the potential to affect obesity prevalence and the health risks associated with

this rapidly growing epidemic in the UK. Furthermore, Magnus et al. (1979) reported that by seasonally interrupting walking, cycling or gardening activities for several months of the year (> 4months) any protective benefits against acute coronary events accumulated by sustained activity throughout the rest of the year are reduced. Therefore with respect to ambulatory activity, walking should be habitually maintained (for ≥ 8 months of the year) for protection to be conferred.

Beyond the physical health benefits of activity there may also be mental health benefits. Mental well-being exhibits seasonality, deteriorating during the winter months (Shin et al. 2005). Maintaining physical activity levels throughout the winter have been shown to somewhat attenuate this seasonal fluctuation (Suter et al. 1991; Huttunen et al. 2004). It is hypothesised therefore that by sustaining daily step counts in the winter there could be benefits for some individuals of improved mood. However, further research is required to evaluate this.

The present study employed two different measures of walking activity, objective step counts and self-reported walking duration. The clear disagreement between the two methods may reflect the inability of self-report to capture ubiquitous walking and everyday activity which has an influential role in preventing unhealthy weight gain (Tudor-Locke and Myers 2001). Time spent walking was greater than time spent in all other leisure-time activities, (which included swimming, football, exercise classes), during both seasons, enforcing the popularity of walking as a means to increase activity levels (Chief Medical Officer 2004).

The summer to winter variation in ambulatory activity reported in this paper, reflect changes in ambient temperature and sunshine hours measured in the UK at the time of each

monitoring frame. Inter-seasonal differences in climate were observed with mean temperature and sunshine hours recorded during the two monitoring frames decreasing by at least three-fold from summer to winter. This was mirrored by a decrease in step counts occurring from summer to winter. Similar observations have been reported with respect to self reported leisure-time activity (Van Staveren et al. 1986; CDC 1997). Rainfall was relatively constant during both seasons, it is noted however that data were available for rainfall volume only, not the number of precipitation days which is in general higher during winter months in the UK (Met Office 2006). A limitation of the current study is the fact that only seasonal summaries of meteorological data were available, and thus it was not possible to statistically assess any relationships between step counts and the climate. Future studies should overcome this shortfall by recording daily weather conditions concurrently with step count data.

Significantly fewer steps were taken on Sundays compared to all other days of the week during both seasons. On average participants took 1,560 steps/day less on a Sunday than all other days of the week during the summer and 1,286 steps/day less during the winter. This finding is consistent with reports from US (Tudor-Locke et al. 2005) and Belgian (Cardon et al. 2006) adults whereby Sunday activity has been noted as significantly lower by 1,250 and 677 steps/day respectively. This simple day of the week activity pattern whereby activity reduces on a Sunday does not appear to be random but an inherent behavioural characteristic of free-living individuals year round across settings. These findings further substantiate the need for physical activity interventions that target Sundays year round (Clemes et al. 2007).

The high mean daily step count standard deviations observed in this paper are characteristic of pedometer based surveillance studies and reflect inter- and intra-individual variability in

behaviour. Other pedometer-based surveillance studies conducted in the USA (Tudor-Locke et al. 2004b), Finland (control group from a physical activity intervention) (Aittasalo et al. 2004), Belgium (Cardon et al. 2006), Australia (Dwyer et al. 2007) and Switzerland (Sequeira et al. 1995) all reported similar levels of daily step count variability, as shown by their reported standard deviations, which were all in the region of 3,000-4,000 steps/day. Similarly, the same studies have shown that high standard deviations remain a characteristic of pedometer data when samples are stratified by gender, age, occupation, self-reported physical activity level, racial grouping, day of the week and BMI.

Due to their self-monitoring nature, long-term free-living pedometer studies are dependent upon participants' honesty and commitment to correctly reporting their daily step count. As all participants used in the current study had previously completed an identical monitoring period in the summer (Clemes et al. 2007), and willingly agreed to take part in the winter follow-up, it is anticipated that this will have minimised any concerns regarding participant commitment and honesty, in terms of step count recording, in these data. In consideration of this point, a limitation of the current study is the fact that participants were all volunteers who were aware at the study outset that they were going to be requested to wear a pedometer and record their daily step counts throughout the monitoring period. It is likely therefore that, due to this self-selection, our participants may have been more motivated than the general population to wear a pedometer over an extended period of time, and to monitor their physical activity. It must be considered therefore that the habitual activity levels of those engaged in this study may have been biased, and the actual step count values reported in this paper may overestimate the general UK population's activity level. Despite this, it is extremely likely that the seasonal trend observed is a true reflection of the general population's experience.

Volunteer based studies often recruit people of a higher socio-economic status (SES). In this sample the SES was relatively diverse. Using participants' postcode to characterise the SES of the area in which they reside, it was observed that our sample came from neighbourhoods where unemployment ranged from 0.8% to 7%, relative to the national average of 3.4%, and the percentage of people in good health, in these neighbourhoods, ranged from 50% to 83%, relative to the national average of 68.8% (Neighbourhood Statistics, 2007). Based upon participants' occupation, 40.6% and 38.5% of our sample can be categorised as white and blue collar workers respectively, while 20.9% of the sample were categorised as non-working (including students, housewives/househusbands, and retired individuals).

The term 'pedometer reactivity' is used to describe any change in walking behaviour that occurs in response to wearing a pedometer, in surveillance studies this issue may be a potential compromise to validity (Clemes et al. 2008b). Currently however there are conflicting findings on the presence/absence of pedometer reactivity in adults (Matevey et al. 2006; Behrens and Dinger 2007; Clemes et al. 2008b). Eastep et al. (2004) have suggested that if pedometer reactivity exists, it will dissipate within approximately two weeks of monitoring. By employing an extensive four-week monitoring frame, habitual activity levels are more likely to be captured. No changes in percent body fat and BMI were seen over either monitoring frames suggesting habitual lifestyle patterns were maintained throughout the two surveillance periods. The sub-study reinforced the seasonal trend (summer steps > winter steps) displayed in the main study, confirming the difference seen between the two seasons was attributable to the season and not a function of reactivity due to participants initial interaction with the pedometer, and step count recording, in the summer of 2005.

Limitations of the current study include the fact that data were collected from only two regions in the UK, from a relatively limited sample size. It would be useful to repeat the study with a larger sample and with a greater number of UK areas represented. Participation was voluntary, therefore at the initial recruitment stage self-selection may have occurred, as discussed above. A further limitation, common to pedometers, is the fact that they do not measure physical activity using only upper body movements, neither do they measure activity associated with cycling or swimming. Results from this pedometer study should therefore be interpreted in context with the study aim; to assess seasonal variation in day-to-day ambulatory activity.

Conclusion

Step counts in the sample of UK adults surveyed decreased significantly in the winter compared to the summer. This has methodological implications for future pedometer research, in that data collection restricted to one season may either overestimate or underestimate year round habitual ambulatory activity. In order to obtain a non-biased reflection of general day-to-day step count levels, pedometer studies should be conducted throughout the year. The current findings from this sample also have health implications, in that public health initiatives aiming to increase overall activity levels should acknowledge likely seasonal changes in ambulatory activity. Information should be disseminated about the possible physiological and psychological health implications of seasonally interrupting activity and effective physical activity policies should be seasonally tailored to provide opportunities to reduce this winter reduction in activity.

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Table I. A summary of the temperature, sunshine hours and rainfall volume recorded during each monitoring frame

	Temperature (oC)			Sunshine hours	Rainfall volume (mm)
	Mean	Min	Max		
Summer 2005	15.9	11.2	20.5	583.3	174.8
Winter 2006	4.0	1.2	6.8	177.9	144.1

Table II. Participant summer and winter anthropometric and step count data

	Summer study		Winter study		Between season differences	
	Mean	SD	Mean	SD	<i>t</i> -value	<i>p</i> -value
BMI (kg/m ²)	26.1	5.1	26.3	5.3	2.372	0.020
% Body fat	25.8	10.4	27.2	10.5	5.722	<0.001
Mean daily step count (steps/day)	10417	3055	9132	2841	6.627	<0.001

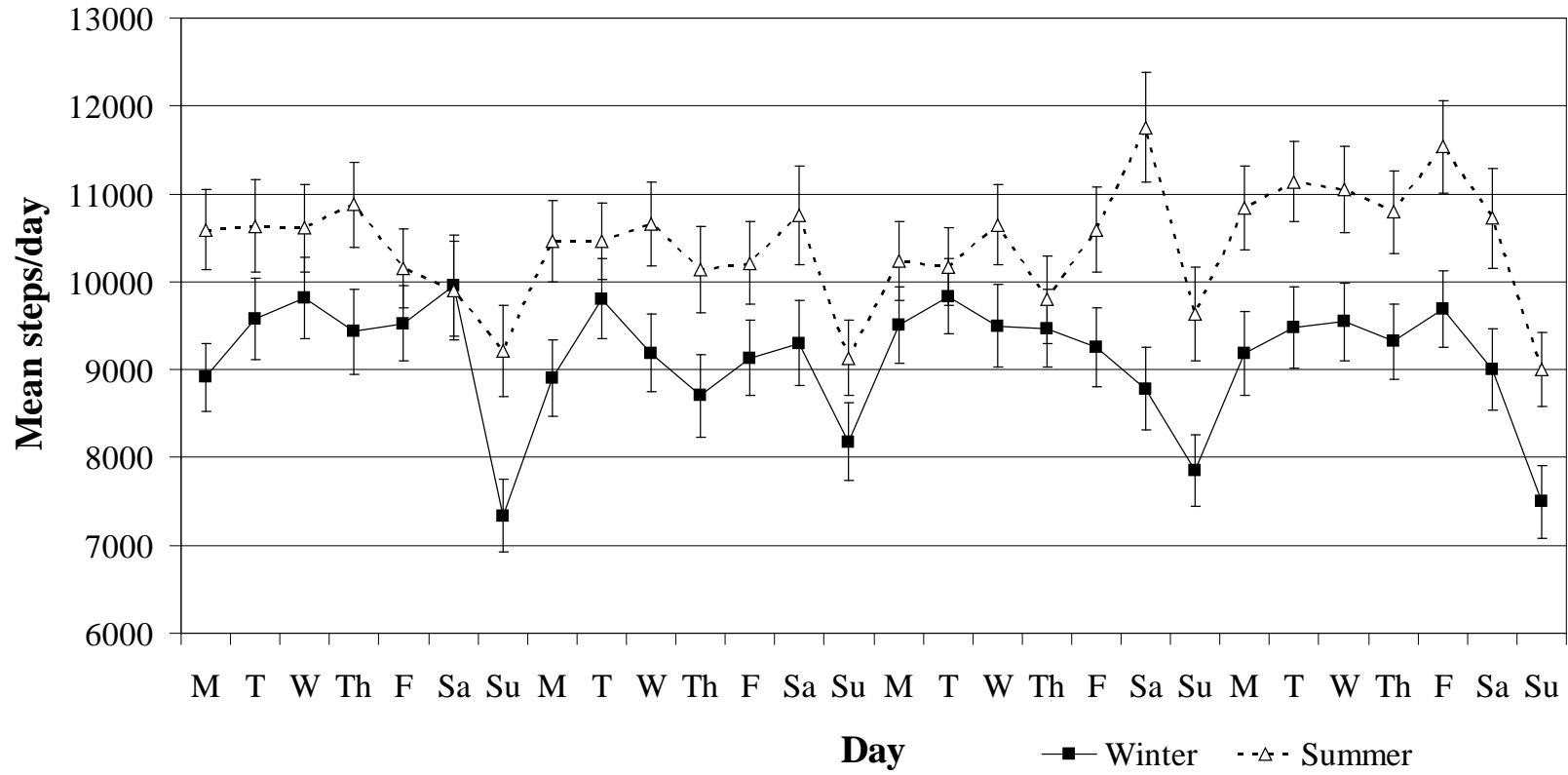


Figure 1. Mean (SE) daily step counts reported over the four-week summer and winter monitoring periods ($n = 96$).

Table III. Mean daily step counts reported on each day of the week over the four-week summer and winter monitoring periods, and day-specific seasonal changes in steps taken (winter minus summer).

Day of Week	Summer steps/day		Winter steps/day		Between season differences		Seasonal change steps/day	
	Mean	SD	Mean	SD	<i>t</i> -value	<i>p</i> -value	Mean	SD
Monday	10531	3728	9128	3422	5.490	<0.001	-1403	2504
Tuesday	10602	3758	9674	3827	3.412	0.001	-928	2664
Wednesday	10741	3882	9511	3692	4.509	<0.001	-1230	2673
Thursday	10402	3810	9233	3684	4.283	<0.001	-1169	2673
Friday	10530	3597	9258	3071	3.770	<0.001	-1273	3181
Saturday	10771	4121	9262	3767	3.828	<0.001	-1509	3863
Sunday	9246	3471	7714	3060	4.090	<0.001	-1532	3671
Day of week main effect	$F=4.593, p<0.01$		$F=7.927, p<0.001$				$F=0.923, p=0.463$	

Bonferroni corrected pairwise comparisons identified Sunday step counts as significantly lower than all other days during both seasons, summer ($p<0.05$) and winter ($p\leq 0.01$).