Summer to winter variability in the step counts of normal weight and overweight adults living in the UK

Running title: Seasonal differences in step counts

Abstract word count: 199

Main text word count: 3928 (excluding title page, abstract and references)

Keywords: seasonality, pedometer, Sunday, body mass index, ambulatory activity

Institutional affiliation of both authors:

School of Sport, Exercise and Health Sciences, Loughborough University

Corresponding Author:

Dr Stacy A Clemes

School of Sport, Exercise and Health Sciences

Loughborough University

Loughborough

Leicestershire

LE11 3TU, UK

Telephone: +44 1509 228170

Fax: +44 1509 223940

Email: S.A.Clemes@lboro.ac.uk

Date of submission: 31st March 2009

Abstract

Background: This study investigated whether pedometer-determined activity varies between summer and winter in normal-weight and overweight adults.

Methods: Forty-five normal-weight (58% female, age=39.1±12.4 years, BMI=22.2±2.1 kg/m^2) and 51 overweight (49% female, age=42.1±12.5 years, BMI=29.3±4.5 kg/m^2) participants completed a within-subject bi-seasonal pedometer study. All participants completed two four-week monitoring periods; one in the summer and one the following winter. Changes in step counts across seasons were calculated and compared for the two BMI groups.

Results: Both BMI groups reported significant summer to winter reductions in step counts, with the magnitude of change being significantly greater in the normal-weight group (-1737±2201 versus -781±1673 steps/day, *P*=0.02). Winter step counts did not differ significantly between the two groups (9250±2845 versus 8974±2709 steps/day, *P*=0.63), whereas the normal-weight group reported a significantly higher mean daily step count in the summer (10986±2858 versus 9755±2874 steps/day, *P*=0.04).

Conclusion: Both normal-weight and overweight individuals experienced a reduction in step counts between summer and winter, however normal-weight individuals appear more susceptible to winter decreases in ambulatory activity, with the greatest seasonal change occurring on Sundays. Effective physical activity policies should be seasonally tailored to provide opportunities to encourage individuals to be more active during the winter, particularly on weekends.

Introduction

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 conducted in both the USA[1-4] and UK.[5] Self-report measures of physical activity can however lack validity in that individuals often exhibit an inability to accurately assess low intensity activities, such as walking behaviour.[6] Walking is reportedly the most prevalent form of physical activity in both US[7] and UK adults,[8] yet it is commonly underestimated through questionnaires.[9-11] By not capturing walking or ambulatory behaviour adequately, self-report studies may lack the sensitivity needed to detect actual seasonal physical activity patterns.

Pedometers are increasingly being used as a surveillance tool to objectively assess free-living ambulatory activity as they provide an accurate and reliable measure of walking behaviour by counting the number of steps taken per day. Limited data currently exists however to describe seasonal changes in the step counts of free-living adults.[12] Due to the increasing public health burden of obesity,[13] and other diseases related to physical inactivity,[14] it is essential to understand activity behaviours of different populations to aid in the development of appropriate public health initiatives.

Differences in pedometer-determined activity levels have been previously reported between different body mass index (BMI) groups,[15-19] with normal weight individuals (BMI < 25 kg/m^2) characteristically reporting higher step counts than their overweight (BMI 25–29.9 kg/m^2) and obese (BMI ≥ 30 kg/m^2)[20] counterparts. In addition, differences in activity patterns over the different days of the week have been reported between normal weight and overweight adults.[15,16] It is currently unknown however whether normal weight and overweight individuals exhibit similar or discrete seasonal activity patterns. A clearer understanding of activity patterns of normal weight and overweight individuals could potentially identify risky behaviours that could be targeted in the design of obesity prevention programmes. The aim of the current study therefore was to investigate whether pedometer-determined activity varies between summer and winter in normal weight and overweight adults living in the UK.

Methods

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 (data collected during this time period have been reported elsewhere[15]) and the second took place six months later during the winter of 2006. This paper details the findings from those participants completing both the summer and winter monitoring frames.

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. Male and female adult participants were recruited using a sampling frame that was developed to achieve an equal 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 kg/m^2) or overweight (BMI ≥ 25 kg/m^2), to reflect the 2001 prevalence of overweight in UK adults.[21]

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. Five participants did not respond to this invitation, whilst 10 met the winter study exclusion criteria which encompassed any non-seasonal lifestyle change made since completion of the summer study which may affect physical activity levels (for example, a change in job (n = 2), moving house during the study period (n = 2), moved house resulting in changes to commuting behaviour (n = 1), divorced and changed leisure time physical activity (n = 1), sustained an injury which influenced walking behaviour (n = 2), and moved away from the area (n = 2)). Ninety-nine participants started the winter monitoring period.

Participants reported being in good general health and none had any physical illnesses or disabilities that might affect their normal daily routine. The study received ethical approval from the Loughborough University Ethical Advisory Committee. Participants were informed about the purpose of the study, they received written and oral information about the study protocol and provided written informed consent.

Measurements of body weight and composition

At the beginning of the study, height was measured without shoes using a wall-mounted stadiometer (Seca UK, Model: 206, Birmingham, Warwickshire, UK). Body weight and percentage body fat were measured using a Tanita Body Composition Analyser (Tanita UK Ltd, Model: BC-418 MA, Middlesex, UK) that measures body fat using 8-point bio-impedance analysis. Percent body fat measured using the Tanita BC-418 has been shown to correlate highly with the reference measure of dual-energy X-ray absorptiometry (DXA).[22] As impedance fluctuates with the distribution of body fluid, to improve accuracy, participants were required to urinate before the measurement of percentage body fat was taken. BMI was calculated as kg/m^2. Measurements of body weight, BMI and percentage body fat were taken at the beginning of the summer and winter monitoring frames.

Pedometer-determined activity

Participants were issued with the same SW-200 pedometer (New Lifestyles, Inc., Lees Summit, MO) during both monitoring periods. This pedometer has been shown to accurately detect steps taken in both free-living conditions[23] and under controlled laboratory conditions using normal weight,[24-26] overweight and obese[27] individuals. The same protocol was employed during both seasons. Participants were instructed to wear the pedometer throughout waking hours for a period of four weeks, only removing it when either bathing, showering or swimming. The appropriate position to wear the pedometer, on the waist band in-line with the midline of the thigh, was shown to participants at the outset. Pedometer accuracy was confirmed with each participant upon issue by means of a 20 step test (acceptance criteria: plus/minus two steps). Each night before going to bed participants recorded the number of steps displayed in an activity log provided. Participants also recorded whether they had gone for a walk that day, along with any participation in sports and/or recreational physical activities. The pedometer was then reset ready for the following day.

All participants were encouraged not to make any changes to their typical daily routine of work and leisure activity. Upon finishing each monitoring period participants completed a brief post-study questionnaire enquiring whether they had suffered from any ill health or made any changes to their normal routine, diet, or general activity levels during the study period.

Meteorological information associated with each monitoring frame

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.[2,28] Data summarising the mean, minimum and maximum temperature (^{o}C), sunshine hours and rainfall volume (mm) were therefore collected retrospectively from the Met Office that corresponded to the summer 2005 and winter 2006 monitoring periods.

Statistical analyses

Statistical analyses were conducted using SPSS for Windows version 16. To ensure the participants completing both monitoring frames did not differ to those completing the summer period only, the two groups were compared in terms of mean summer step counts, pre-summer study BMI and gender distribution using independent samples *t*-tests and Chi-squared statistics.

Summer and winter mean daily step counts were calculated over each four-week monitoring frame for the normal weight (BMI <25 kg/m^2) and overweight (BMI ≥25 kg/m^2) participants. To test for an overall effect of season, and for an interaction between seasonal change in steps and weight status, a two-way mixed ANOVA was conducted with season (summer and winter mean steps) as the within-subjects factor and weight status as the between subjects factor (normal weight versus overweight). Mean daily step counts reported by the normal weight and overweight groups in each season were also compared using an independent t-test and effect sizes of the differences in step counts reported between groups were calculated.[29] For the normal weight and overweight participants the percent change in step counts between seasons were calculated by dividing the mean seasonal change in steps (winter minus summer) by mean daily step counts reported in the summer, multiplied by 100. For each group mean step counts reported on each specific day of the week were calculated for each season by averaging the 4 step count values available for each day. Using these data a repeated-measures ANOVA with Bonferroni corrected post hoc comparisons were applied to test whether mean step counts differed between days within each season. 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 sample *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). The measurements of body weight, percent body fat and BMI were compared between seasons using paired-samples t tests. Statistical significance was set at $P<0.05$.

Follow-up-study

A sub-sample of participants from the main study (n = 28, normal weight: n = 17, overweight: n = 11) 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 of normal weight and overweight participants, during each of the three monitoring frames, were compared using a repeated measures ANOVA, with Bonferroni corrected comparisons applied in the event of a significant seasonal effect.

Results

Meteorological information

Meteorological data recorded by the Met Office for Cornwall and Leicestershire, along with the national average for England, during the monitoring periods (summer 2005, winter 2006, summer 2006) are shown in Table 1. Due to the relatively small size of the country, large differences in climate between regions do not exist. Large climate-related differences in activity between our participants recruited from Cornwall and Leicestershire were therefore not anticipated and no significant differences in mean daily step counts were observed between participants from each location in either season (Summer: Leicestershire sample = 10837±3119 steps/day versus Cornwall sample = 10056±2966 steps/day, P=0.213; Winter: Leicestershire sample = 9729±2685 steps/day versus Cornwall sample = 8709±3027 steps/day, P=0.09).

Insert Table 1 about here

Participants

Of the 99 participants who started the winter monitoring period, 3 were lost at follow-up. Ninety-six participants (78.6% of those used in the analysis of the summer monitoring period) therefore 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 ($P>0.05$, data not shown).

Forty-five normal weight and 51 overweight participants completed the two monitoring periods. Demographic characteristics of the normal weight and overweight groups are shown in Table 2, along with a summary of the seasonal activity data reported by participants in each group. Participants provided 5324 person-days of pedometer data, of a possible 5376 (99% compliance). There were no significant differences between the normal weight and overweight participants in terms of the number of days the pedometer was worn during each season (Summer: normal weight = 27.6±0.7 days versus overweight = 27.8±0.6 days, $P=0.10$; Winter: normal weight = 27.7±0.7 days versus overweight = 27.7±0.7 days, $P=0.66$). Furthermore, the number of days in which the pedometer was worn did not differ significantly between the two seasons for either participant group ($P>0.05$). All participants remained in good health during the summer and winter monitoring periods and no changes to daily routine or lifestyle were reported.

Insert Table 2 about here

The normal weight participants exhibited no significant changes in body weight and BMI between the summer and winter monitoring periods, however a significant increase in percentage body fat was observed in the winter in this group ($t=2.4$, $P<0.02$) (Table 2). In comparison, significant increases in body weight, BMI and percentage body fat were observed between the summer and winter monitoring periods in the overweight group (all $P<0.05$) (Table 2).

Differences in summer and winter step counts

Results of the two-way mixed ANOVA revealed a significant overall effect of season, with both groups exhibiting significant reductions in mean step counts between summer and winter ($F=40.3$, $P<0.001$). Normal weight participants showed a consistent summer to winter reduction in mean step counts on every day of the week (Table 3), with this group reporting an overall mean winter reduction in ambulatory activity of 1736 steps/day (effect size = 0.62). The overweight group reported an overall mean winter reduction in ambulatory activity of 781 steps/day (effect size = 0.43). A significant interaction effect of BMI group was observed, with the normal weight group exhibiting a significantly larger winter reduction in mean daily step counts in comparison with the overweight group ($F=5.8$, $P=0.02$) (Figure 1). The normal weight participants exhibited on average a 15.4% reduction in step counts in the winter in comparison with a 6.9% reduction in steps seen in the overweight group ($t=2.49$, $P=0.02$, effect size = 0.25). During the summer monitoring period, the normal weight participants reported a significantly higher mean daily step count than the overweight group ($t=2.1$, $P=0.04$, effect size = 0.21), however no statistically significant differences in mean step counts were observed between the two BMI groups during the winter monitoring period ($t=0.49$, $P>0.05$) (Figure 1).

Insert Figure 1 about here

Day-of-the-week variations in step counts

No significant variations in step counts were observed in the normal weight group over the different days of the week during the summer monitoring period ($F=2.1$, $P>0.05$) (Table 3). A significant day-of-the-week effect was observed in this group however during the winter monitoring frame ($F=4.4$, $P<0.001$), with step counts reported on a Sunday being significantly lower than those reported on all other days (all $P<0.002$). In the overweight group a significant day-of-the-week effect was observed during both seasons (summer: F=4.2, $P<0.001$; winter: F=3.8, $P<0.001$), with step counts reported on a Sunday being significantly lower than those reported on all other days of the week during summer and winter (all $P<0.002$) (Table 3).

Insert Table 3 about here

Follow-up study

Participants who completed the follow-up study (normal weight: n = 17, overweight: n = 11) did not differ significantly from the remainder of the sample with regards to summer 2005 and winter 2006 mean daily step counts (all $P>0.05$, data not shown). Significant differences in mean daily step counts were observed across the three seasons in the normal weight participants (summer 2005 = 11213±2399 steps/day, winter 2006 = 9554±2952 steps/day, summer 2006 = 11085±3222 steps/day, F=9.98, $P<0.001$), with post hoc analyses revealing that step counts reported in the winter of 2006 were significantly lower than those reported during both summers (2005 and 2006). No significant overall effect of season was observed in the follow-up sample of overweight participants (summer 2005 = 9245±2271 steps/day, winter 2006 = 8260±2289 steps/day, summer 2006 = 8701±2052 steps/day, F=1.92, $P=0.172$),

Discussion

The aim of this study was to determine whether pedometer-determined activity varies between summer and winter in normal weight and overweight adults. Reductions in ambulatory activity were observed in both BMI groups in the winter monitoring period, and this was accompanied by significant increases in percentage body fat measured in the winter relative to the summer in both groups. The magnitude of seasonal change in activity was greater in the normal weight participants studied suggesting that normal weight individuals are more prone to seasonal fluctuations in ambulatory activity. The changes in ambulatory activity observed in the current study reflect changes in ambient temperature and sunshine hours measured in the UK at the time of each monitoring frame, supporting previous evidence suggesting that seasonal changes in physical activity are mediated through changes in the environment,[2,28] particularly the weather.[30]

The observed changes in ambulatory activity are consistent with seasonal changes in activity reported in questionnaire-based surveys of physical activity,[1-5] accelerometer-determined physical activity[31] and pedometer-determined activity, whereby a sample of adults living in the US reported winter reductions in step counts.[12] This paper is the first of its kind however to distinguish between normal weight and overweight adults, living in the UK, when describing seasonal patterns in ambulatory activity.

The findings from the follow-up sample of normal weight participants studied in the summer of 2006 showed that this group of participants increased their activity levels, relative to the winter monitoring period, the following summer. No significant differences in step counts recorded between the two summer monitoring periods (2005 and 2006) were observed in this group demonstrating that these normal weight individuals re-attained their increased activity levels the following summer. Whilst this follow-up sample did not differ significantly from the rest of the sample in terms of summer 2005 and winter 2006 step counts, it is not possible to determine whether the same pattern was observed in the normal weight participants who did not complete the follow-up study. Indeed, seasonal changes in activity could have potential health consequences if such individuals do not re-attain their activity levels the following summer. Whilst a winter reduction in mean daily step counts was observed, in comparison with the two summer monitoring periods, in the follow-up sample of overweight participants the magnitude of seasonal change was not statistically significant supporting the observation made from the whole sample of overweight participants that overweight individuals appear to be less susceptible to seasonal changes in activity. Encouraging overweight individuals to make the most of the summer weather by increasing their activity levels to the level observed among the normal weight participants during this season could be an effective starting point for strategies aimed at reducing the prevalence of obesity in the UK.

Whilst the normal weight participants showed a consistent summer to winter reduction in mean step counts on every day of the week, the greatest seasonal change in steps appeared to occur on Sundays for this group. The mean reduction in steps between the summer and winter monitoring period on Sunday was 2503 steps/day. It was evident that the normal weight group maintained their activity levels throughout the week during the summer, as no day-of-the-week effects occurred during this monitoring frame. However, during the winter period step counts were significantly lower for this group on a Sunday in comparison with all other days. As the majority of participants who completed this study worked Monday through to Friday, it is likely that the step counts reported on Saturdays and Sundays are reflective of general lifestyle and leisure-time activities. Public health messages and the provision of suitable in-door facilities that encourage activity on a Sunday during the winter months could potentially reduce the magnitude of seasonal changes in activity observed in the normal weight participants surveyed. The development of such facilities and public health messages may also be effective in encouraging overweight individuals to increase their activity levels on a Sunday, given the decreases in activity that were also seen in this group on this particular day of the week across both seasons.

In addition to highlighting differences in seasonal activity between normal weight and overweight adults, 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, particularly in normal weight adults. For example, in the summer monitoring period 60% of the normal weight group reported mean daily step counts above the recommended 10,000 steps/day, this figure fell to 36% in the winter monitoring period. The proportion of overweight participants achieving at least 10,000 steps/day during the summer and winter monitoring periods were 43% and 35% respectively. Similar to the findings of Tudor-Locke et al,[12] we observe that in order to obtain a non-biased reflection of general day-to-day step count levels, pedometer studies should either be conducted throughout different time points over the year, or restricted to spring or fall to avoid the summer peaks and winter troughs in activity reported herein.

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 by recording daily weather conditions concurrently with step count data. Another limitation is the fact that data were collected from a self-selected sample. The current findings should therefore be confirmed in, preferably a random sample of adults, recruited from a number of regions throughout the UK. Furthermore, the size of the follow-up sample assessed in the summer of 2006 was relatively small in comparison to the sample size of the main study which potentially led to a lack of statistical power to detect differences between the seasons in the overweight group. 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 study should therefore be interpreted in context with the study aim; to assess seasonal variation in ambulatory activity.

Despite these limitations, this study was the first of its kind to describe seasonal patterns in ambulatory activity, measured objectively, in a sample of normal weight and overweight adults living in the UK. Given daily step counts measured in normal weight, overweight and obese adults living in the UK,[16] and in other European countries[32,33] tend to be higher by approximately 3000 to 4000 steps/day, than those observed in US adults,[18,19,34,35] it is important to understand habitual activity levels and patterns in different populations to aid in the formulation of appropriate, population-specific, public health messages. Furthermore, given the diverse global climate, and as seasonal changes in physical activity are thought to be partly mediated through changes in the weather,[2,28,30] it is likely that seasonal patterns in ambulatory activity may vary between countries, and more regionally specific studies are necessary if we are to understand global patterns in activity. A strength of our study is the four-week monitoring frame applied in both seasons which increases the likelihood that we have captured participants habitual activity and any reactivity effects, a potential validity threat to short-term pedometer studies[36,37] have been minimised.

In conclusion, step counts in the sample of UK adults surveyed decreased significantly in the winter compared to the summer, with the normal weight participants appearing more susceptible to winter decreases in ambulatory activity. Public health messages that encourage overweight adults to take advantage of the warmer weather during the summer months by increasing their activity levels during this season could be an effective starting point for strategies aimed at reducing the prevalence of obesity in the UK. Effective physical activity policies should be seasonally tailored to provide opportunities to encourage individuals to be more active during the winter. For example, encouraging physical activity, through indoor activities, particularly on a Sunday could potentially reduce the magnitude of seasonal changes seen in normal weight adults, and may also help to encourage overweight adults to increase their activity levels on this particularly in-active day of the week.

References

1. Dannenberg AL, Keller JB, Wilson PW, Castelli WP. Leisure time physical activity in the Framingham Offspring Study. Description, seasonal variation, and risk factor correlates. *Am J Epidemiol.* 1989;129(1):76-88.
2. CDC. Monthly estimates of leisure-time physical inactivity--United States, 1994. *MMWR Morb Mortal Wkly Rep.* 1997;46(18):393-7.
3. Matthews CE, Freedson PS, Hebert JR, Stanek EJ, Merriam PA, Rosal MC, et al. Seasonal variation in household, occupational, and leisure time physical activity: longitudinal analyses from the seasonal variation of blood cholesterol study. *Am J Epidemiol.* 2001;153(2):172-83.
4. Pivarnik JM, Reeves MJ, Rafferty AP. Seasonal variation in adult leisure-time physical activity. *Med Sci Sports Exerc.* 2003;35(6):1004-8.
5. Uitenbroek DG. Seasonal variation in leisure time physical activity. *Med Sci Sports Exerc.* 1993;25(6):755-60.
6. Sallis JF, Saelens BE. Assessment of physical activity by self-report: status, limitations, and future directions. *Res Q Exerc Sport.* 2000;71(2 Suppl):S1-14.
7. Simpson ME, Serdula M, Galuska DA, Gillespie C, Donehoo R, Macera C, et al. Walking trends among U.S. adults: the Behavioral Risk Factor Surveillance System, 1987-2000. *Am J Prev Med.* 2003;25(2):95-100.
8. Chief Medical Officer. At least five a week: evidence on the impact of physical activity and its relationship to health. Crown Copyright. 2004.
9. Richardson MT, Leon AS, Jacobs DR, Ainsworth BE, Serfass R. Comprehensive evaluation of the Minnesota Leisure Time Physical Activity Questionnaire. *J Clin Epidemiol.* 1994;47(3):271-81.
10. Ainsworth B, Leon A, Richardson M, Jacobs D, Paffenbarger RJ. Accuracy of the College Alumnus Physical Activity Questionnaire. *J Clin Epidemiol.* 1993;46(12):1403-11.

11. Bassett DR, Cureton AL, Ainsworth BE. Measurement of daily walking distance-questionnaire versus pedometer. *Med Sci Sports Exerc.* 2000;32(5):1018-23.

12. Tudor-Locke C, Bassett DR, Swartz AM, Strath SJ, Parr BB, Reis JP, et al. A preliminary study of one year of pedometer self-monitoring. *Ann Behav Med.* 2004;28(3):158-62.

13. James PT. Obesity: the worldwide epidemic. *Clin Dermatol.* 2004;22(4):276-80.

14. Allender S, Foster C, Scarborough P, Rayner M. The burden of physical activity-related ill health in the UK. *J Epidemiol Community Health.* 2007;61(4):344-8.

15. Clemes SA, Griffiths PL, Hamilton SL. Four-week pedometer-determined activity patterns in normal weight and overweight UK adults. *Int J Obes (Lond).* 2007;31(2):261-6.

16. Clemes SA, Hamilton SL, Lindley MR. Four-week pedometer-determined activity patterns in normal-weight, overweight and obese adults. *Prev Med.* 2008;46:325-30.

17. Thompson DL, Rakow J, Perdue SM. Relationship between accumulated walking and body composition in middle-aged women. *Med Sci Sports Exerc.* 2004;36(5):911-4.

18. Tudor-Locke C, Ainsworth BE, Whitt MC, Thompson RW, Addy CL, Jones DA. The relationship between pedometer-determined ambulatory activity and body composition variables. *Int J Obes Relat Metab Disord.* 2001;25(11):1571-8.

19. Tudor-Locke C, Ham SA, Macera CA, Ainsworth BE, Kirtland KA, Reis JP, et al. Descriptive epidemiology of pedometer-determined physical activity. *Med Sci Sports Exerc.* 2004;36(9):1567-73.

20. World Health Organisation. Obesity: Preventing and managing the global epidemic: Report of a WHO consultation. Geneva: WHO Technical Report Series 894. 2000.

21. Department of Health. Health Survey for England 2001. London: The Stationary Office; 2003.

22. Pietrobelli A, Rubiano F, St-Onge MP, Heymsfield SB. New bioimpedance analysis system: improved phenotyping with whole-body analysis. *Eur J Clin Nutr.* 2004;58(11):1479-84.

23. Schneider PL, Crouter SE, Bassett DR. Pedometer Measures of Free-Living Physical Activity: Comparison of 13 Models. *Med Sci Sports Exerc.* 2004;36(2):331-5.

24. Schneider PL, Crouter SE, Lukajic O, Bassett DR. Accuracy and Reliability of 10 Pedometers for Measuring Steps Over a 400-m Walk. *Med Sci Sports Exerc.* 2003;35(10):1779-84.

25. Crouter SE, Schneider PL, Karabulut M, Bassett DR. Validity of 10 Electronic Pedometers for Measuring Steps, Distance, and Energy Costs. *Med Sci Sports Exerc.* 2003;35(8):1455-60.

26. Le Masurier GC, Tudor-Locke C. Comparison of Pedometer and Accelerometer Accuracy Under Controlled Conditions. *Med Sci Sports Exerc.* 2003;35(5):867-71.

27. Swartz AM, Bassett Jr. DR, Moore JB, Thompson DL, Strath SJ. Effects of Body Mass Index on the Accuracy of an Electronic Pedometer. *International Journal of Sports Medicine.* 2003;24(8):588-92.

28. Merrill RM, Shields EC, White GL, Druce D. Climate conditions and physical activity in the United States. *Am J Health Behav.* 2005;29(4):371-81.

29. Field A. Discovering statistics using SPSS. London: Sage; 2005.

30. Tucker P, Gilliland J. The effect of season and weather on physical activity: a systematic review. *Public Health.* 2007;121(12):909-22.

31. Buchowski M, Choi L, Majchrzak K, Acra S, Matthews CE, Chen K. Seasonal changes in amount and patterns of physical activity in women. *Journal of Physical Activity and Health.* 2009;6:252-61.

32. Sequeira MM, Rickenbach M, Wietlisbach V, Tullen B, Schutz Y. Physical activity assessment using a pedometer and its comparison with a questionnaire in a large population survey. *Am J Epidemiol.* 1995;142(9):989-99.

33. Aittasalo M, Miilunpalo S, Suni J. The effectiveness of physical activity counseling in a work-site setting. A randomized, controlled trial. *Patient Educ Couns.* 2004;55(2):193-202.

34. Tudor-Locke C, Burkett L, Reis JP, Ainsworth BE, Macera CA, Wilson DK. How many days of pedometer monitoring predict weekly physical activity in adults? *Prev Med.* 2005;40(3):293-8.

35. Chan CB, Ryan DA, Tudor-Locke C. Health benefits of a pedometer-based physical activity intervention in sedentary workers. *Prev Med.* 2004;39(6):1215-22.

36. Clemes SA, Matchett N, Wane SL. Reactivity: an issue for short-term pedometer studies? *Br J Sports Med.* 2008;42(1):68-70.

37. Clemes SA, Parker RA. Increasing our understanding of reactivity to pedometers in adults. *Med Sci Sports Exerc.* 2009;41(3):674-80.

Table 1

A summary of the mean temperature, sunshine hours and rainfall volume recorded in Cornwall and Leicestershire, along with the national average for England, by the Met Office during the Summer of 2005, Winter 2006 and Summer 2006.

Location		Temperature (^{o}C)			Sunshine hours	Rainfall volume (mm)
		Mean	Min	Max		
Cornwall	Summer 2005	15.6	11.4	19.9	619.9	210.2
	Winter 2006	4.4	1.6	7.2	180.0	236.8
	Summer 2006 (follow-up)	16.5	12.0	21.1	688.2	155.9
Leicestershire	Summer 2005	15.9	11.1	20.7	577.4	169.8
	Winter 2006	3.8	1.1	6.6	173.0	119.8
	Summer 2006 (follow-up)	17.2	12.0	22.4	654.1	152.8
England	Summer 2005	15.9	11.2	20.5	583.3	174.8
	Winter 2006	4.0	1.2	6.8	177.9	144.1
	Summer 2006 (follow-up)	17.0	12.0	22.0	676.4	154.2

Table 2

Demographic characteristics of the normal weight and overweight participants along with each groups mean daily step counts, minutes reported walking and minutes reported engaged in sports and/or recreational physical activities during the summer 2005 and winter 2006 monitoring frames. Data are mean (SD) values unless otherwise stated.

	Normal weight participants (n = 45)				Overweight participants (n = 51)			
	Summer Mean (SD)	Winter Mean (SD)	Seasonal change	Within group differences (p value)	Summer Mean (SD)	Winter Mean (SD)	Seasonal change	Within group differences (p value)
Age (years)	39.1 (12.4)				42.1 (12.5)			
Height (cm)	168.8 (10.5)				169.5 (9.7)			
Percent female	58%				49%			
Percent from Cornwall	40%				51%			
Body weight (kg)	63.3 (9.0)	63.3 (9.2)	0	0.988	83.8 (11.5)	84.7 (11.8)	0.9	0.013
BMI (kg/m^2)	22.2 (2.1)	22.2 (2.2)	0	0.984	29.3 (4.6)	29.6 (4.6)	0.3	0.015
Percent body fat	20.5 (9.0)	21.5 (8.6)	1.0	0.020	30.2 (9.5)	31.8 (9.7)	1.6	<0.001
Overall seasonal mean steps/day	10986 (2858)	9250 (2845)	-1736	<0.001	9755 (2874)	8974 (2709)	-781	0.002
Medium (IQR) minutes reported walking/day*	18.7 (7.3, 30.8)	8.5 (1.9, 20.1)	-10.2	0.001	12.1 (3.2, 22.0)	4.4 (0, 13.9)	-7.7	0.03
Medium (IQR) minutes reported in other activities/day*	7.7 (0.5, 21.3)	6.1 (0, 25.2)	-1.6	0.688	4.3 (0, 17.1)	1.1 (0, 17.7)	-3.2	0.442

* due to skewed data, the median and inter-quartile ranges are reported for the self-reported time spent walking, and time engaged in other recreational physical activities data. Within group seasonal differences in time spent walking and time engaged in other activities were

compared using the Wilcoxon Signed Ranks Test. Paired t-tests were used for the remaining within-group comparisons reported in the table.

Table 3

Mean (SD) daily step counts reported on each day of the week by the normal weight and overweight participants during the summer 2005 and winter 2006 monitoring frames.

	Normal weight participants (n = 45)				Overweight participants (n = 51)			
	Summer Mean (SD)	Winter Mean (SD)	Seasonal change	Within group differences (p value)	Summer Mean (SD)	Winter Mean (SD)	Seasonal change	Within group differences (p value)
Monday	10524 (3412)	9006 (3249)	-1518	<0.001	10223 (3305)	9055 (3202)	-1168	0.001
Tuesday	11176 (3481)	9666 (3465)	-1510	<0.001	9850 (3323)	9457 (3593)	-393	0.236
Wednesday	11026 (3547)	9716 (3705)	-1310	0.007	10165 (3509)	9201 (3209)	-964	0.011
Thursday	10929 (3555)	9138 (3443)	-1791	<0.001	9732 (3845)	9222 (3674)	-510	0.111
Friday	11177 (3197)	9495 (3029)	-1682	<0.001	9913 (3430)	9232 (3352)	-681	0.114
Saturday	11733 (3714)	9901 (4447)	-1832	0.004	10089 (4329)	9014 (3702)	-1075	0.063
Sunday	10327 (3526)	7824 (3143)	-2503	<0.001	8312 (3162)	7637 (3017)	-675	0.184
Within group/season differences	p >0.05	p <0.001*			p <0.001*	p <0.001*		

* within group differences, mean daily step counts reported on a Sunday were significantly lower than those reported on all other days of the week by the normal weight group during the winter, and by the overweight group during both summer and winter.

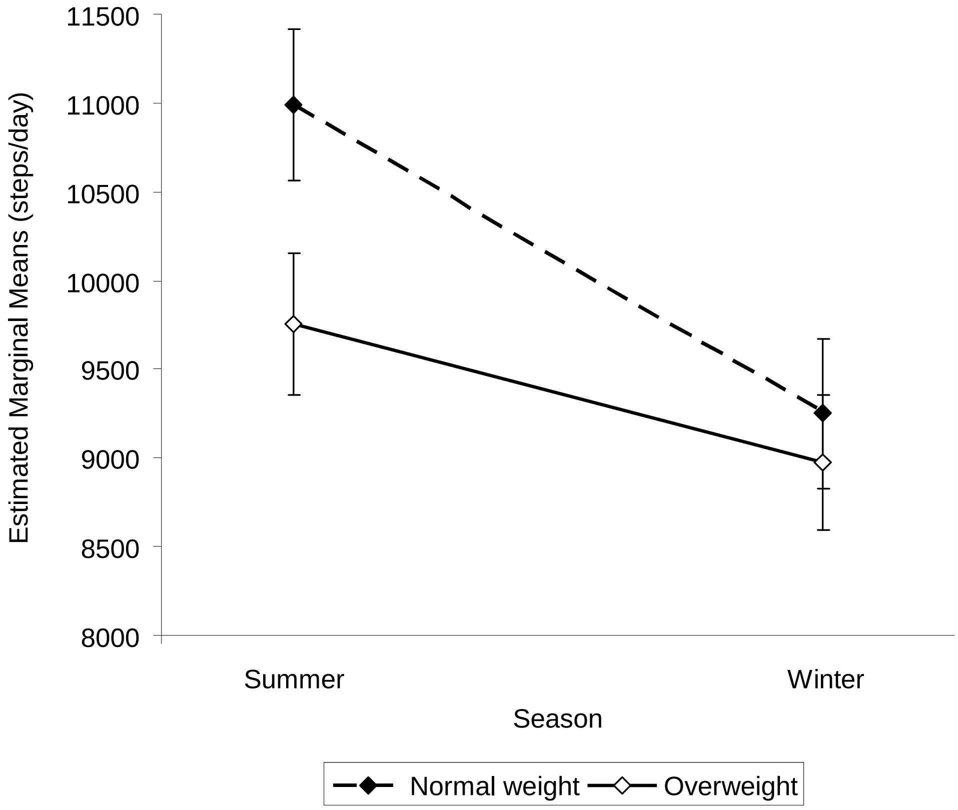

Figure 1. Estimated marginal means, with standard error bars, showing the interaction between season (mean step counts reported in the summer and winter) and weight status (normal weight versus overweight).