Seasonal variation in total energy expenditure and physical activity in Dutch young adults

Seasonal Variation in Total Energy Expenditure and Physical Activity in Dutch Young Adults

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Abstract

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Objective: The impact of season on energy expenditure and physical activity is not well quantified. This study focused on summer-winter differences in total energy expenditure (TEE) and physical activity.

Research Methods and Procedures: Twenty-five healthy Dutch young adults, living in an urban environment, were measured in the summer season and the winter season. TEE was measured using doubly labeled water, and sleeping metabolic rate (SMR) was measured during an overnight stay in a respiration chamber. Subsequently, the physical activity level (PAL = TEE/SMR) and activity-related energy expenditure [(0.9 × TEE) − SMR] were calculated. Maximal mechanical power (W_{max}) was determined with an incremental test on a cycle ergometer. Body composition was measured with hydrostatic weighing and deuterium dilution using Siri's three-compartment model.

Results: There was no difference in TEE between seasons. PAL was higher in summer than in winter (1.87 ± 0.22 vs. 1.76 ± 0.18; $p < 0.001$), and the difference was higher for men than for women (0.20 ± 0.14 vs. 0.05 ± 0.16; $p = 0.04$). The difference in PAL between seasons was dependent on the initial activity level. There was a strong linear relation ($R^2 = 0.48$) between PAL and physical fitness (W_{max}/fat-free mass), but W_{max}/fat-free mass did not change between seasons in response to the lower PAL in winter.

Discussion: The extent of the changes in PAL is of physiological significance, and seasonality in physical activity should be taken into account when studying physical activity patterns or relationships between physical activity and health.

Key words: doubly labeled water, physical activity level, maximal mechanical power, physical fitness, seasonality

Introduction

Physical activity is the most variable component of total energy expenditure (TEE)[1] among subjects and, therefore, is important in the regulation of energy balance. Seasonal changes in physical activity might influence energy balance and, as a consequence, body mass. The impact of season on energy metabolism has been investigated in developing countries, where both energy intake and energy expenditure can vary considerably between harvest and nonharvest seasons, resulting in changes in body weight (1–3). Studies in industrialized countries also show changes in body weight (4–7) over the year, implying a change in energy intake, energy expenditure, or both. Studies investigating seasonal changes in energy intake have shown contradictory results (4–6). The lack of an accurate method to determine energy intake probably accounts for the inconsistent results. TEE and its different components, resting metabolic rate (RMR), diet-induced thermogenesis (DIT), and activity-related energy expenditure (AEE), can be measured much more accurately. The gold standard for measuring TEE is the doubly labeled water method. In combination with a measure of RMR, the doubly labeled water method allows one to calculate the physical activity level (PAL = TEE/RMR) and

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[1] Nonstandard abbreviations: TEE, total energy expenditure; RMR, resting metabolic rate; DIT, diet-induced thermogenesis; AEE, activity-related energy expenditure; PAL, physical activity level; VO_{2max}, maximal oxygen uptake; W_{max}, maximal mechanical power; SMR, sleeping metabolic rate; FFM, fat-free mass; BM, body mass.

AEE. Because of the high cost of ^{18}O, this method is not applicable for large studies. Therefore, most seasonality studies assess physical activity by means of self-report (5,6,8,9), pedometry (4), or accelerometry (8). These studies indicate lower physical activity during the winter season, but the impact on energy metabolism is not well quantified. Schoeller and Hnilicka (10) have measured TEE with doubly labeled water and have found no difference in TEE between summer and winter in six women. A study by Haggarty et al. (11) has also included measurements of TEE and RMR in nine adult men, but has found no significant differences in TEE, basal metabolic rate, or PAL. The investigators do suggest, however, that individuals with the highest activity level in summer exhibit the greatest decrease in activity in winter.

If season causes significant changes in physical activity, this might also be reflected in a change in physical fitness. Ingemann-Hansen and Halkjaer-Kristensen (12) have found a higher maximal oxygen uptake (VO_{2max}) for subjects measured in summer than in winter, but these data are cross-sectional.

Several studies have demonstrated seasonality in blood pressure (13), as well as plasma lipids, with higher levels of cholesterol (14,15), low-density lipoproteins (or apoB) (15,16), and high-density lipoproteins (15) in winter than in summer. In addition, cardiovascular disease and mortality show a winter peak (17–19). In this regard, information on seasonal variations in physical activity is highly relevant.

Because of the wide interest in seasonal influences on physical activity and the small number of data available in terms of energy expenditure, we were interested in intra- and interindividual changes in TEE, PAL, and AEE between seasons in both men and women. Furthermore, we aimed to investigate seasonality in physical fitness and the relation between physical activity and physical fitness.

Research Methods and Procedures

Subjects

Subjects were 25 healthy volunteers (10 men and 15 women) between the ages of 20 and 30 years, most of whom worked at the Maastricht University. Detailed information about the objective and the protocol of the study was provided to each subject. Written informed consent was obtained, and the study was approved by the Ethics Committee of Maastricht University. Subjects participated in a study investigating seasonality in body weight and the underlying mechanisms. Combined measurements of sleeping metabolic rate, body weight, body composition, maximal mechanical power (W_{max}), and TEE were recorded in the summer (July and August) and the winter (January and February).

One subject was excluded from all analyses because of illness and subsequent weight loss in the winter season. One subject was excluded from the analyses regarding physical fitness because of an incomplete test on the cycle ergometer in the summer season, caused by pain in the knee.

Subjects' characteristics at the time they entered the study are shown in Table 1.

Table 1. Subject characteristics at baseline as mean ± SD

	Women	Men
N	15	9
Age (years)	25 ± 2	26 ± 2
Height (m)	1.72 ± 0.07	1.83 ± 0.08
Body mass (kg)	64.4 ± 5.9	70.1 ± 9.8
BMI (kg/m^2)	21.9 ± 1.9	20.8 ± 2.1
Body fat (%)	26.1 ± 5.5	15.0 ± 2.7

Sleeping Metabolic Rate

Sleeping metabolic rate (SMR) was measured during an overnight stay in a respiration chamber. The chamber measured 14 m^3 and was equipped with a bed, table, chair, freeze toilet, washing bowl, radio, television, and computer (20). Subjects entered the room at 9:00 PM and left the room at 7:30 AM. Energy expenditure was calculated from O_2 consumption and CO_2 production according to Weir's formula (21). SMR was defined as the average metabolic rate during at least 3 hours of sleep, with the lowest activity measured by Doppler radar. Subjects were asked to consume their normal evening meal at home between 6:00 PM and 7:00 PM. The meals were not standardized, so as not to interfere with the subjects' normal feeding behavior and, thus, energy balance. Because SMR was measured at least 6 hours, normally 8 to 11 hours, after the meal, the effect of diet-induced thermogenesis was assumed to be minimal (22). Subjects were instructed to refrain from intensive exercise the day before their stay in the respiration chamber. Room temperature was held constant at 20 ± 1 °C for both seasons. SMR was used for the calculation of PAL and AEE. Extensive results about SMR are discussed elsewhere (23).

Body Composition

Anthropometric measurements were taken in the morning after subjects left the respiration chamber. Body mass was measured on an electronic scale (Mettler Toledo ID1 Plus; Giessen, Germany) to the nearest 0.01 kg. Height was measured to the nearest 0.1 cm (Mod.220; SECA, Hamburg, Germany). Body volume was measured with underwater weighing. Residual lung volume was simultaneously measured using the helium dilution technique. Total body water was measured with deuterium dilution according to the Maastricht protocol (24).

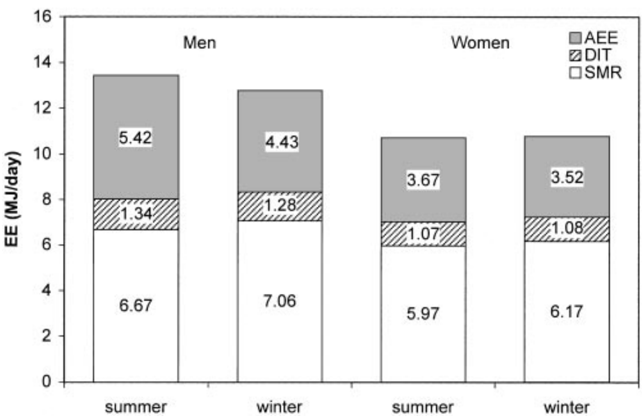

Figure 1: TEE and its components, SMR, DIT (10% of TEE), and AEE, for men and women in the summer and winter seasons.

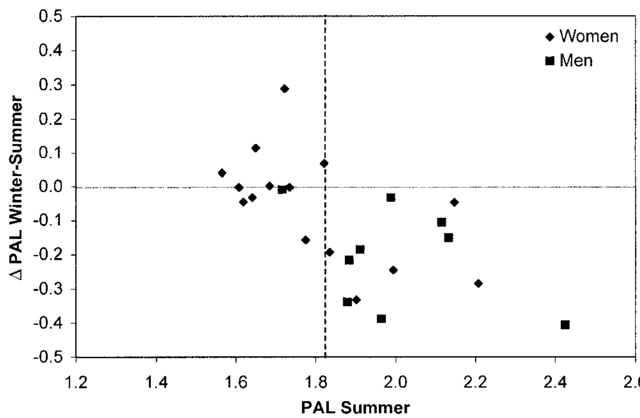

Figure 2: Difference in PAL between winter and summer seasons against the initial PAL (summer). The vertical dashed line represents the mean PAL of the whole group over both seasons. All subjects with a higher PAL in summer than the group mean showed a decreased PAL in winter.

Body composition was calculated from body density and total body water using Siri's three-compartment model (25).

TEE

TEE was measured with doubly labeled water according to the Maastricht protocol (24). In short, after the collection of a baseline urine sample (day 0), subjects drank a weighed amount of $^{2}H_2{}^{18}O$, resulting in an initial excess body water enrichment of 150 ppm for deuterium and 300 ppm for oxygen-18. Subsequent urine samples were collected in the morning of days 1, 8, and 15 and in the evening of days 1, 7, and 14.

W_{max}

W_{max} was determined during an incremental test on a cycle ergometer according to the protocol of Kuipers et al. (26). After a warm-up of 5 minutes at 100 W for men and 75 W for women, workload was increased by 50 W every 2.5 minutes. When heart rate exceeded 160 beats/min or the respiratory quotient exceeded 1, workload was increased by 25 W every 2.5 minutes until exhaustion.

W_{max}/fat-free mass (FFM) was used as a measure of physical fitness.

Statistics

Differences between summer and winter were tested using ANOVA repeated measures, with sex as a "between-subjects" factor. To investigate the relation between physical activity and physical fitness, linear regression analysis was performed. Statistical significance was set at $p < 0.05$. All analyses were done with Statview 5.0 for Macintosh (SAS Institute, Cary, NC).

Results

There was no difference in TEE (megajoules per day) between the summer and winter seasons for men (13.43 ± 2.73 vs. 12.77 ± 2.39) or women (10.71 ± 1.48 vs. 10.77 ± 1.65; Figure 1). There was a significant seasonal effect on PAL, with higher PAL levels in summer and lower levels in winter (1.87 ± 0.22 vs. 1.76 ± 0.18; $p < 0.001$). The average PAL was not different between sexes ($p = 0.07$), but the difference between seasons was significantly higher for men than for women (0.20 ± 0.14 vs. 0.05 ± 0.16; $p = 0.04$). The PAL values for men and women, respectively, were 2.00 ± 0.22 and 1.79 ± 0.20 in summer and 1.80 ± 0.18 and 1.74 ± 0.17 in winter. The higher PAL was also reflected in a higher AEE value (megajoules per day) in summer compared with that in winter (4.33 ± 1.63 vs. 3.86 ± 1.35; $p = 0.02$). Mean AEE was significantly higher for men than for women ($p = 0.02$; Figure 1), and the difference between seasons was higher for men than for women ($p = 0.03$; Figure 1). When AEE was corrected for body mass (BM; AEE/BM), the difference between seasons ($p < 0.01$) was still present, and the difference was higher for men than for women ($p < 0.01$). The average AEE/BM was also higher for men ($p = 0.04$). When AEE was corrected for FFM (AEE/FFM), the sex difference disappeared. The seasonal difference was still present ($p < 0.01$), but the difference was no longer higher for men than for women ($p = 0.08$).

The difference in PAL between seasons was dependent on the initial (summer) activity level. The more active the subjects were during the summer, the greater the reduction in activity was in the winter, whereas those who were inactive in the summer remained inactive in winter (Figure 2).

There was a strong linear relation between PAL and W_{max}/FFM (watts per kilogram; $R = 0.64$, $p = 0.001$ in summer; $R = 0.57$, $p = 0.005$ in winter) and AEE and W_{max}/FFM ($R = 0.62$, $p = 0.002$ in summer; $R = 0.60$, $p = 0.003$ in winter) in both seasons. Because intercept and

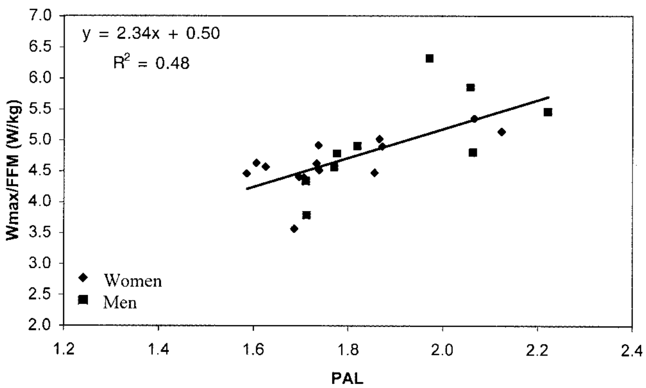

Figure 3: Linear regression of physical fitness (W_{max}/FFM; mean values over both seasons) against the physical activity level (PAL; mean values over both seasons). Men and women (indicated with different symbols) were combined in the regression analysis.

slope were not significantly different between seasons, the average values of both seasons were used in a simple regression analysis, resulting in a correlation of 0.69 ($R^2 = 0.48$, $p < 0.001$) between PAL and W_{max}/FFM (Figure 3) and a correlation of 0.66 ($R^2 = 0.43$, $p < 0.001$) between AEE and W_{max}/FFM. Despite the lower PAL and AEE in winter, physical fitness did not change between seasons (4.76 ± 0.64 in summer vs. 4.78 ± 0.58 in winter).

Discussion

TEE was not significantly different between seasons, but PAL and AEE measurements were significantly different. The drop in PAL toward the winter season was highest for those subjects with the highest activity level in summer. The change in physical activity did not result in a change in physical fitness.

The finding that TEE was not significantly different between seasons is in agreement with the study of Haggarty et al. (11), who have found a difference in TEE of 0.98 MJ/d (not significant) between summer and winter in nine adult men. However, we did find a significantly lower PAL in the winter than in the summer season, which was more pronounced for men than for women. The average PAL over both seasons was 1.82, which is higher than the population average of ~1.77 (27,28). This is because of the high activity level in summer, whereas in winter, the PAL dropped to the population average. Because we used SMR to calculate PAL, values might have been slightly higher compared with studies using RMR. However, there is no general consensus that RMR is, in fact, higher than overnight SMR (29,30). Even so, given the longitudinal approach of our study, this would not have affected any of the results.

These results indicate that the outcome of research about PALs in relation to other variables may be highly dependent on the time of year that the measurements take place. Seasonal differences were higher for men than for women, which is mainly attributable to the higher PAL (2.0) for men in the summer season compared with that for women (1.79) and the population average (1.77). In concurrence with PAL, AEE was significantly different between seasons, even after correction for BM or FFM.

Haggarty et al. (11) have found a PAL of 2.01 in summer vs. 1.88 in winter. The fact that this difference is not significant might be because of the low number of subjects ($n = 9$), a problem inherent in the use of doubly labeled water. They have stated, however, that the three subjects with the highest TEE exhibited the greatest reduction in expenditure in winter. In our study, the most active subjects in summer showed the greatest decrease in PAL in winter. When subjects were divided into "high-activity" and "low-activity" groups by taking the average PAL of all subjects over both seasons, all subjects in the high-activity group showed a drop in PAL in winter, whereas in the low-activity group, subjects were equally distributed around the line of "zero change" (Figure 2). In other words, the more active subjects were in the summer season, the less likely they were to maintain their activity level in the winter season. This is, perhaps, not very surprising because of the substantially shorter day length and worse weather conditions in winter. This would especially influence the time spent in outdoor activities. Most subjects in this study were working at the university, performing comparable activities that were independent of season. The difference in activity levels is, therefore, caused by leisure time activity, including sports and nonsport activities. Westerterp (31) has shown that PAL is positively related to time spent in moderate-intensity activities, negatively related to time spent in low-intensity activities, and not related to time spent in high-intensity activities. This finding implies that PAL is mainly determined not by sports activities, but by nonsport moderate-intensity activities, such as walking or cycling. It might be these activities, in particular, that are decreased in the winter season, resulting in a lower PAL. This is confirmed by a study of Matthews et al. (8), who have measured 580 subjects by means of three different 24-hour physical activity recalls administered five times over 12 months. They have found peak values for total physical activity as well as moderate-intensity activity in July, whereas low-intensity activity peaks in January, and high-intensity activity peaks in January and May for men and women, respectively. Therefore, it can be hypothesized that in winter, even though active people try to compensate for the drop in moderate-intensity activities by sports activities, they are unable to maintain the same PAL as in the summer.

We are aware that part of the observed decrease in PAL in winter is explained by an increased SMR. For both men and women, SMR was significantly higher in winter than in summer (6.51 vs. 6.23; ANOVA, $p < 0.0001$), but the difference between seasons was not significantly different between sexes ($p = 0.14$). Possible reasons for the observed seasonal difference in SMR, including ambient temperature, are described elsewhere (23). Despite the increased SMR, TEE did not increase accordingly, resulting in a lower amount of energy spent on activity (AEE) and a lower PAL.

The coefficient of variation (CV) of doubly labeled water measurements in free-living subjects is ~8%, which is caused largely by a 7% physiological variation. The analytic variation is, therefore, variable among laboratories (~1% to 2%) (10). Given the small differences observed for women and the sensitivity of the doubly labeled water method, it is important to interpret these results with care. Although statistically significant for the entire group, the differences in PAL and AEE were present mainly for men, probably because of the high PAL observed for men in the summer (Figure 2).

Because there is no method available to accurately assess food intake or diet composition, no measure of energy intake was included. We assumed DIT to be 10% of TEE in both seasons. Even if DIT were higher in the winter season because of an increased energy intake, this would result in an even lower AEE and, therefore, would not affect our conclusion.

Regression analysis showed a strong linear relation between W_{max}/FFM and PAL as well as AEE. This indicates that the overall PAL and the net amount of energy spent on activity are strong predictors of physical fitness. However, despite the lower PAL in winter, W_{max}/FFM remained the same in both seasons. There is an ongoing discussion about whether physical activity or physical fitness is more important in relation to certain health outcomes, such as cardiovascular disease, and, therefore, whether physical fitness can be used as a measure of average daily activity (32–34). Physical activity is the main determinant of physical fitness, although there is a large genetic component. Because physical activity is often measured by means of self-report, whereas physical fitness is usually measured more objectively, physical fitness often provides stronger associations with health outcomes (34). Furthermore, the fact that PAL and AEE were significantly lower in the winter than in the summer season indicates that the time of the activity measurement can highly influence the outcome. W_{max}/FFM, on the other hand, did not change over seasons, despite the lower activity. Therefore, physical fitness is more resistant to "short-term" environmental influences, in this case season, than physical activity is and might provide a better measurement of "overall" activity in relation to health. The fact that physical fitness is unaffected by season, in contrast to physical activity, is also shown in the correlation between summer and winter, which was 0.94 for W_{max}/FFM and 0.63 for PAL. This suggests that physical fitness is a more long-term reflection of daily physical activity for normally active, nonathletic subjects. It is also possible that the genetic component in physical fitness explains the maintained fitness level or that subjects perform high-intensity, but less energy-consuming, activities in winter.

Several studies have demonstrated seasonality in blood pressure (13) and plasma lipids, with higher levels of cholesterol (14,15), low-density lipoproteins (or apoB) (15,16), and high-density lipoproteins (15) in the winter than in the summer. In addition, cardiovascular disease and mortality show a winter peak (17–19). It is well known that regular physical activity can positively affect these cardiovascular risk factors and, therefore, lower the risk for cardiovascular mortality. The coincidence between seasonality in cardiovascular risk factors and physical activity suggests a causal relationship. Magnus et al. (35) have reported a negative correlation between acute coronary events and habitual light physical exercise when performed for >8 mo/yr. The correlation disappears when the activities are interrupted for several months (<8 mo/yr) and, thus, are seasonal in nature. Mundal et al. (13) have stated that the seasonal variation in blood pressure, both during rest and during exercise, may be explained by a parallel seasonal variation in physical fitness. Douglas et al. (19) have investigated seasonality among different death causes and have found that the amplitude was highest for respiratory disease, immediately followed by circulatory diseases including ischemic heart disease and cerebrovascular disease. Changes in climatic features, such as ambient temperature, are very likely to be related to higher mortality rates in the winter but certainly cannot be the only factor. The higher blood pressure, lower cardiac output and stroke volume, and higher heart rate in winter observed by Izzo et al. (36) may be related to lower activity levels observed in this study.

PAL was dependent on season, whereas physical fitness did not change. On the other hand, seasonality in certain cardiovascular risk factors may be related to lower activity levels, implying that, despite the same level of physical fitness, lower PALs during certain months of the year may be an independent risk factor.

Some studies have found a seasonal variation in physical fitness (12,13). The complexity in defining physical fitness may contribute to the contrary results that have been found. We defined physical fitness as W_{max} corrected for FFM. W_{max} is linearly correlated with VO_{2max}, the most widely used fitness measure, with only a deviation in the extreme upper part of the curve. Therefore, we believe that our fitness measure is sufficiently accurate. The correction for FFM was made because FFM is a major determinant of W_{max} and also to correct for sex differences in body composition.

The use of doubly labeled water provided accurate information about total physical activity and energy expenditure over 14 days and revealed quite substantial seasonal differences, especially in men. The high costs related with this method make the data on this topic very scarce, and this scarcity of data emphasizes the uniqueness of this study. A disadvantage is the lack of information on activity patterns.

In conclusion, we found a significant seasonal variation in PAL with lower activity levels in winter. The most active subjects in summer failed to maintain their activity level in winter. We believe that the extent of the changes in PAL is of physiological significance and that seasonality in physical activity should be taken into account when studying relationships between physical activity and health or when studying the seasonality in cardiovascular risk factors.

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