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International Journal of Obesity (2008) 32, 1264–1270
 0307-0565/08 $30.00
www.nature.com/ijo

ORIGINAL ARTICLE

Body composition is associated with physical activity in daily life as measured using a triaxial accelerometer in both men and women

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Background: Activity-related energy expenditure is the most variable component of total energy expenditure and thus an important determinant of energy balance.
Objective: To determine whether body composition is related to physical activity in both men and women.
Design: A total of 134 healthy participants were recruited (80 women, 54 men; aged 21 ± 2 years; body mass index, 22.0 ± 2.4). Physical activity was measured for a period of 2 weeks using a triaxial accelerometer for movement registration (Tracmor). Percentage body fat (%BF) was determined by underwater weighing and deuterium dilution according to Siri's three-compartment model.
Results: The participant characteristics—body mass, height and gender together explained a substantial part of the variation in %BF ($R^2=0.75$, SEE = 4.0%). Adding physical activity to the model increased the explained variation in %BF with 4% ($R^2=0.79$, SEE = 3.7%, $P<0.001$). Taking seasonality into account by adding the number of daylight hours as an independent variable further increased the explained variation with 1% ($R^2=0.80$, SEE = 3.7%, $P<0.05$). In analogy, the association was evaluated for both genders separately. In women, %BF and physical activity were significantly associated ($P<0.001$). In men, %BF was only associated with physical activity when seasonality was taken into account as well ($P<0.05$). This probably resulted from men participating more in season bound sports, because an association was found without adjusting for seasonality when only men with a consistent year-round participation in sports were considered.
Conclusion: Evidence was found for an association between body composition and physical activity in both genders. A consistent year-round degree of physical activity appears to be a prerequisite to reveal the association. Moreover, Tracmor-assessed physical activity improves the estimate of %BF when a participant's characteristics are taken into account.
International Journal of Obesity (2008) **32,** 1264–1270; doi:10.1038/ijo.2008.72; published online 27 May 2008

Keywords: physical activity; body composition; accelerometry

Introduction

In Westernized societies, the prevalence of obesity is still increasing,[1,2] thereby increasing the population's risk for secondary diseases like type 2 diabetes mellitus, cardiovascular diseases and several types of cancer.[3–6] Obesity develops when energy intake exceeds energy expenditure for a prolonged period of time. In free-living humans, activity related energy expenditure is the most variable component of total energy expenditure.[7] Physical activity level (PAL), that is, the factor by which total energy expenditure exceeds resting energy expenditure, was shown to range from 1.2 to 2.5 for completely sedentary and very physically active lifestyles, respectively.[8,9] Physical activity thus sets the upper limit for total energy expenditure.[10] Consequently, a reduced physical activity is a potentially important risk factor for a positive energy balance that could ultimately result in the onset of obesity.[11–16]

Previously, an association between body composition and physical activity-related energy expenditure has been shown in men but not in women.[17,18] Westerterp and Goran concluded that the association was probably not observed in women due to an increased energy intake to compensate for a higher degree of physical activity. Furthermore, a 16 months exercise intervention resulted in a significant loss of fat mass in men, whereas fat mass was not decreased in women.[19] This supports the idea that women compensate for an increased total energy expenditure by increasing their energy intake more than men do.[17] However, Westerterp and

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Received 29 August 2007; revised 6 March 2008; accepted 20 April 2008; published online 27 May 2008

Goran[18] recruited women aged 19–49 and Paul *et al.*[17] recruited women with an average age of 48 ± 10 years. When Stubbs *et al.*[20] increased energy expenditure over a period of 7 days by implementing 80 min of exercise per day in women aged 23 ± 0.6 years, they did not find any compensation in energy intake. This suggests that whether or not women compensate their energy intake to meet energy expenditure may depend on age. Consequently, the lack of association between body composition and physical activity related energy expenditure in women may represent an age effect. Therefore, the aim of the present study was to determine the association between %BF and physical activity in a population of young men and women, with physical activity measured objectively during a prolonged period of time using a validated triaxial accelerometer.

Methods

Participants

A total of 134 healthy, nonsmoking participants (80 females, 54 males) aged 21 ± 2 years were recruited to participate in this study. Participants were weight stable for at least 6 months and were not using any medication except for oral contraceptives. Recruitment was carried out using flyers in the university building. Information about the purpose and protocol of the study were provided both orally and in writing. All participants provided written informed consent before participating in the study. The study conformed to the standards set by the Declaration of Helsinki and the local Ethics Committee approved the study. We certify that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during this research. Participant characteristics ($n = 134$) are presented in Table 1.

Table 1 Subject characteristics

	Males	*Females*
N	54	80
Age (years)	21 ± 2	21 ± 2
Body mass (kg)	76.1 ± 9.9	63.1 ± 7.9†
Height (m)	1.85 ± 0.06	1.70 ± 0.06†
BMI (kg per m^2)	22.3 ± 2.4	21.8 ± 2.5
%BF	14.0 ± 5.5	26.3 ± 5.1†
Physical activity (Mcnts per day)	3789 ± 813	3773 ± 816
PAL	1.82 ± 0.13	1.82 ± 0.13
%Low	97.3 ± 1.2	97.0 ± 1.2
%Moderate	2.0 ± 0.8	2.3 ± 0.9
%High	0.7 ± 0.6	0.7 ± 0.5
Sports (h per week)	2.9 ± 2.2	2.4 ± 1.9

BMI, body mass index; %BF, percentage body fat; Physical activity, physical activity in daily life as measured using a triaxial accelerometer during a period of 2 weeks; Mcnts per day, megacounts per day; PAL, physical activity level; %Low, %Moderate and %High, proportion of time subjects were physically activity at a low, moderate and high intensity, respectively; Sports, time spent on sports in hours per week. Values are mean ± s.d. Significant difference between genders: †$P < 0.001$.

Body composition

%BF was determined as a measure for body composition. Therefore, anthropometric measurements were carried out in the morning after an overnight fast. Body mass was measured on an electric scale (ID 1 Plus; Mettler Toledo, 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 determined using the underwater weighing technique while correcting for residual lung volume using the helium dilution technique (Volugraph VG 2000; Mijnhardt, Bunnik, The Netherlands). Total body water was determined overnight using the deuterium dilution technique according to the Maastricht protocol.[21] Body composition was subsequently calculated from body volume and total body water using Siri's three-compartment model.[22]

Physical activity

Physical activity was measured using a triaxial accelerometer for movement registration (Tracmor IV; Philips Research, Eindhoven, The Netherlands) sensitive to a wide range of body movements. The accelerometer has been validated against doubly labeled water, the gold standard for measuring energy expenditure in daily life.[23] The Tracmor registers accelerations of the trunk along the antero-posterior, medio-lateral and longitudinal axis using three uniaxial piezo-electric accelerometers (details are provided elsewhere[23]). To ensure a valid reflection of long-term daily life activities, the accelerometer was worn for 14 days under free-living conditions.

Participants were instructed to wear the Tracmor from the moment they woke up in the morning until they went back to bed at night. To verify whether participants lived up to this instruction, waking hours and clock times of wearing the Tracmor were noted. To make sure only representative days were included, the difference between the total time the participant was awake and the time the accelerometer was worn was not allowed to exceed 75 min per day. The few days during which this difference exceeded 75 min were excluded from the analysis.

Physical activity was acquired by summing the output of all three axes and is presented as megacounts per day (Mcnts per day). Using Tracmor data, the proportion of time participants were physically active at a low, moderate and high intensity (%Low, %Moderate and %High, respectively) was determined. The cut-off points for the intensity categories were determined in a pilot study ($n = 5$). The cut-off point for low-intensity physical activity was set by Tracmor outputs associated with walking on a treadmill at 3.5 km h^{-1}, which corresponds with approximately three metabolic equivalents (METs). For moderate-intensity physical activity, a Tracmor output associated with walking on a treadmill at 5 km h^{-1} was used, which corresponds with approximately 4.5 METs.[24] The relevant Tracmor outputs were 16.0 ± 3.0 megacounts per minute (Mcnts per min) and

28.9 ± 3.0 Mcnts per min, respectively. All physical activity associated with a Tracmor output higher than the latter cut-off point was considered high-intensity physical activity. The proportion of time per intensity category was calculated as the sum of all minutes per intensity category divided by the total duration of the measurement, that is, 14 days minus the number of excluded days.

Using linear regression analysis in a population similar to the present study with respect to physical activity, body composition and age, Plasqui *et al.*[23] were able to predict PAL with an explained variation of 70% using only the Tracmor output. This regression equation was used in the present study to estimate PAL.

Statistics

Differences between genders were tested using Student's *t*-tests for unpaired samples. Multiple linear regression analysis was used to test the association between %BF and physical activity. Body mass, height and gender were taken into account as known predictors.[25] Furthermore, Plasqui *et al.* previously showed that PAL is higher in summer than in winter. In the present study, physical activity was monitored round the year. Therefore, the effect of seasonality was taken into account using the number of relevant daylight hours for the 2 weeks monitored.[26] The association between %BF and the proportion of time spent on physical activity of low, moderate and high intensity was determined using multiple linear regression. The association between %BF and physical activity was determined for each gender separately, taking body mass and height into account. The models obtained using multiple linear regression were checked for (multi)-collinearity using the variance inflation factor.

Statistical analysis was carried out using the Statistical Package for Social Sciences (SPSS) version 11 for Macintosh OS X (SPSS Inc., Chicago, Illinois, USA). Data are expressed as mean ± s.d. P values <0.05 were considered statistically significant.

Results

There was no significant difference between the physical activity of men and women (Table 1). However, the number of daylight hours during the 2 weeks monitored was significantly higher in women: 11.7 ± 2.9 versus 9.5 ± 2.0 h per day ($P<0.001$). After adjusting for seasonality, physical activity was significantly higher in men ($P<0.001$). PAL values ranged from 1.50 to 2.27 with a mean of 1.82 ± 0.13 (Table 1). There was no difference between the proportion of

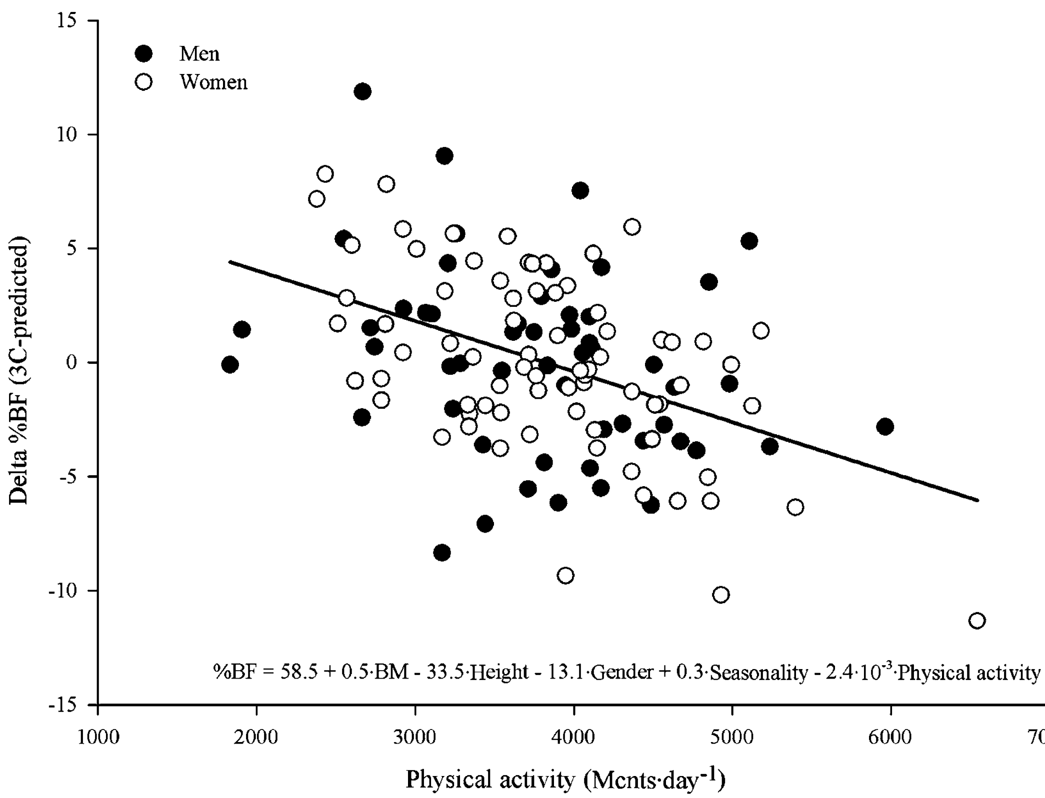

Figure 1 The residual of percentage body fat that cannot be explained by body mass, height, gender and seasonality as a function of physical activity ($P<0.001$). BM, body mass in kg; height in m; gender, 0 for women, 1 for men; seasonality, the average number of daylight hours during the 2 weeks monitored; physical activity, physical activity in daily life as measured using a triaxial accelerometer during a period of 2 weeks in megacounts per day (Mcnts per day).

time spent in each intensity category by men and women. Body mass and height were significantly higher in men ($P<0.001$). Whereas body mass index (BMI) was comparable between genders, %BF was significantly higher in women ($P<0.001$) (Table 1).

The participant characteristics—body mass, height and gender together explained a large part of the variation in %BF ($R^2=0.75$, standard error of the estimate (SEE) = 4.0%). Still, adding physical activity to the model significantly increased the explained variation in %BF with 4% ($R^2=0.79$, SEE = 3.7%, $P<0.001$), with %BF negatively associated with physical activity (Figure 1). A significant positive association was observed between physical activity and the number of daylight hours during the 2 weeks monitored ($P<0.01$). Adding the number of daylight hours to the model to take seasonality into account further increased the explained variation in %BF with 1% (Table 2).

Adding %Low, %Moderate or %High to a regression model with body mass, height and gender as independent variables, significantly increased the explained variation in %BF for each intensity category ($P<0.001$, $P<0.01$ and $P<0.001$, respectively). %BF was positively associated with %Low and negatively with %Moderate and %High (Figure 2). Of the three intensity categories, only %Low and %Moderate were significantly associated with seasonality (negatively, $P<0.001$ and positively, $P<0.001$, respectively).

When analyzing both genders separately, a discrepancy was observed in the association between physical activity and seasonality. In women, no association was found ($P=0.2$) whereas in men there was ($P<0.001$). In women, body mass and height together explained 41% of the variation in %BF ($R^2=0.41$, SEE = 3.9%). Adding physical activity to the model significantly increased the explained variation in %BF with 17% (Table 3). Adding the number of daylight hours as an independent variable did not further improve the model. In men, 46% of the variation in %BF can be explained by body mass and height (Table 3). Adding physical activity only improved the model if seasonality was taken into account as well (Table 3). Approximately two out of three sports practiced by men were highly season bound with a peak in the summer season, compared with one out of three in women. When the analysis was repeated for men who either did not participate in sports or participated for at least 9 months per year ($n=30$), adding physical activity to a model with body mass and height significantly improved the explained variation in %BF with 7% without adjusting for seasonality ($R^2=0.60$; SEE = 4.3%; $P<0.05$). When only data for the remaining men were analyzed, that is, those participating in sports but for less than 9 months per year ($n=24$), physical activity did not contribute to the explained variation in %BF ($P>0.9$).

Table 2 Unstandardized regression coefficients, 95% CIs and *P*-values with percentage body fat as the dependent variable

	B	*95% CI for B*		P
	$R^2=0.80$, SEE = 3.7%			
Constant	58.5			
Body mass (kg)	0.5	0.4	0.6	2.3×10^{-20} †
Height (m)	−33.5	−45.1	−22.0	6.7×10^{-8} †
Gender (F = 0, M = 1)	−13.1	−15.1	−11.0	6.8×10^{-24} †
Physical activity (Mcnts per day)	-2.4×10^{-3}	-3.0×10^{-3}	-2.0×10^{-3}	8.3×10^{-7} †
Seasonality (daylight hours)	0.3	0.1	0.6	1.9×10^{-2} *
	$R^2=0.77$, SEE = 3.9%			
Constant	−54.0			
Body mass (kg)	0.5	0.4	0.5	1.4×10^{-17} †
Height (m)	−32.2	−44.5	−19.9	8.4×10^{-7} †
Gender (F = 0, M = 1)	−13.8	−15.9	−11.7	1.0×10^{-24} †
%Low	1.1	0.5	1.7	3.3×10^{-4} †
	$R^2=0.76$, SEE = 4.0%			
Constant	53.3			
Body mass (kg)	0.4	0.4	0.5	1.6×10^{-16} †
Height (m)	−30.8	−16.0	−11.6	3.9×10^{-6} †
Gender (F = 0, M = 1)	−13.3	−15.6	−11.1	7.4×10^{-24} †
%Moderate	−1.1	−2.0	−0.3	6.7×10^{-3} §
	$R^2=0.77$, SEE = 3.9%			
Constant	59.5			
Body mass (kg)	0.5	0.4	0.6	2.7×10^{-18} †
Height (m)	−36.0	−48.3	−23.6	6.1×10^{-8} †
Gender (F = 0, M = 1)	−13.2	−15.3	−11.1	9.4×10^{-24} †
%High	−2.6	−3.9	−1.2	2.4×10^{-4} †

Abbreviations: B, unstandardized regression coefficient; 95% CI for B, 95% confidence interval for B; %Low, %Moderate and %High, proportion of time subjects were physically active at a low, moderate and high intensity, respectively; Mcnts per day, megacounts per day; Physical activity, physical activity in daily life as measured using a triaxial accelerometer during a period of 2 weeks; Seasonality, the average number of daylight hours during the 2 weeks monitored; SEE, standard error of the estimate. Statistically significant association: *$P<0.05$; §$P<0.01$; †$P<0.001$.

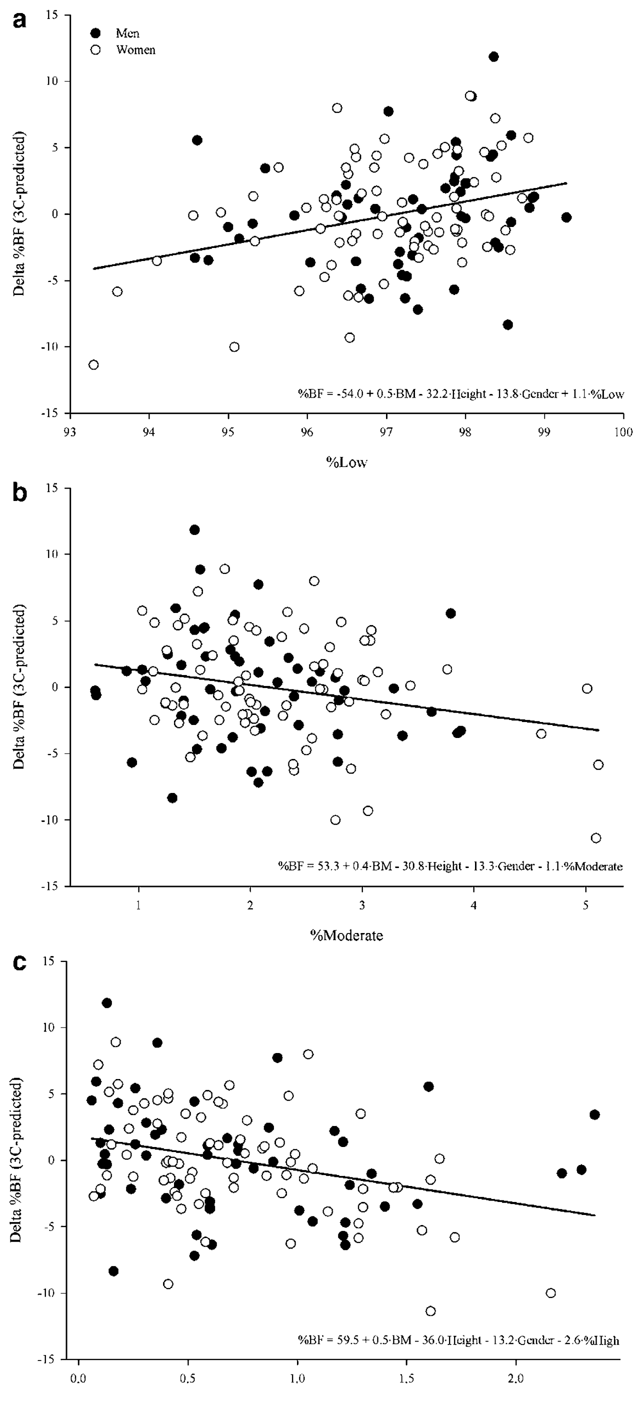

Figure 2 The residual of percentage body fat that cannot be explained by body mass, height and gender as a function of the proportion of time participants were physically active at low- (**a**, $P<0.001$), moderate- (**b**, $P<0.01$) and high intensity (**c**, $P<0.001$), respectively. BM, body mass in kg; height in m; gender, 0 for women, 1 for men; %Low, %Moderate and %High, the proportion of time participants were physically active at a low, moderate and high intensity, respectively.

Discussion

The aim of this study was to determine whether body composition is associated with physical activity in both genders. Therefore, %BF was determined in a population of 134 young adults using underwater weighing and deuterium dilution according to Siri's three-compartment model. Physical activity was determined in daily life during a prolonged period of time using a triaxial accelerometer for movement registration. Evidence was found for an association between %BF and physical activity in both men and women.

In a study population consisting of 747 adults, Deurenberg *et al.*[25] previously showed that the participant characteristics—BMI, age and gender together explained 79% of the variation in %BF measured by underwater weighing. Similar results were obtained here, although in the present study, age did not contribute significantly to the model. A small range in age in the present study can explain this discrepancy. As physical activity is known to decrease with increasing age,[8,27] the age range of 18–27 can probably also explain why the average PAL of 1.82 found here is higher than the previously reported population average of 1.77.[8,28] In a population with a comparable range in age, Plasqui *et al.*[29] also found an average PAL of 1.82. The range in PAL from 1.50 to 2.27 found in the present population indicates that both sedentary and physically active participants were included.

Adding physical activity to a model with body mass, height and gender as independent variables, added a significant 4% to the explained variation in %BF. This implies that with basic participant characteristics taken into account, %BF was significantly associated with physical activity. %BF was also positively associated with %Low and negatively with %Moderate and %High. In other words, %BF was negatively associated with all physical activities with a higher intensity than that associated with walking at $3.5\,\mathrm{km\,h^{-1}}$. Exchanging physical activity for PAL in the model in Table 2 indicates that when assuming causality, an increase of 0.1 in PAL, decreases %BF with 1.5% (data not shown). As was shown in Table 1, the distribution of BMI in the present population was quite narrow. It can be argued that with a higher range in BMI, the association between %BF and physical activity would have been even stronger.

Adjusting the association between %BF and physical activity for seasonality by adding the number of daylight hours as an independent variable further increased the explained variation in %BF with 1%. Physical activity was monitored round the year and was previously shown to be higher in summer than in winter.[29] The longitudinal results from Plasqui *et al.* were confirmed here, because a significant positive association was observed between physical activity and the number of daylight hours during the 2 weeks monitored.

Analyzing the results for both genders separately showed an association between %BF and physical activity in women but not in men. However, seasonal differences in physical

Table 3 Unstandardized regression coefficients, 95% CIs and *P*-values with percentage body fat as the dependent variable for both genders separately

	B	*95% CI for B*		P
Women		$R^2=0.58$, SEE = 3.3%		
Constant	48.1			
Body mass (kg)	0.4	0.4	0.6	2.4×10^{-12} †
Height (m)	−23.7	−36.7	−10.6	5.6×10^{-4} †
Physical activity (Mcnts per day)	-2.6×10^{-3}	-4.0×10^{-3}	-2.0×10^{-3}	2.7×10^{-7} †
Men		$R^2=0.52$, SEE = 3.9%		
Constant	58.1			
Body mass (kg)	0.5	0.3	0.6	7.2×10^{-9} †
Height (m)	−42.7	−63.6	−21.9	1.4×10^{-4} †
Seasonality (daylight hours)	0.6	-1.5×10^{-2}	1.2	5.5×10^{-2}
Physical activity (Mcnts per day)	-1.9×10^{-3}	-3.0×10^{-2}	0	2.2×10^{-2} *

Abbreviations: B, unstandardized regression coefficient; 95% CI for B, 95% confidence interval for B; Mcnts per day, megacounts per day; Physical activity, physical activity in daily life as measured using a triaxial accelerometer during a period of 2 weeks; Seasonality, the average number of daylight hours during the 2 weeks monitored; SEE, standard error of the estimate. Statistically significant association: *$P<0.05$; †$P<0.001$.

activity were previously shown to be higher in men than in women.[29] In the present population, analyzing the data for men and women separately resulted in an association between physical activity and the number of daylight hours in men only. Consequently, taking seasonality into account by adding the number of daylight hours to a model with body mass, height and physical activity as independent variables did not increase the explained variation in %BF in women. In men on the other hand, taking seasonality into account was a prerequisite for an association between %BF and physical activity to be revealed. Plasqui *et al*.[29] attributed the higher seasonal differences in physical activity in men compared with women to a higher PAL for men in the summer season. Furthermore, Plasqui *et al*. concluded from their data that the more active participants were in summer, the less likely it was they maintained their activity level in the winter season. Due to the cross sectional design of the present study, no conclusions about intra-individual seasonal differences in physical activity can be drawn. However, approximately two out of three sports practiced by men were highly season bound with peaks in the summer season, compared with only one out of three in case of women. This difference may explain why, in the present study, physical activity was only associated with seasonality in men and why taking seasonality into account was required in men for the association between %BF and physical activity to be revealed. Indeed, when repeating the analysis for men with a consistent year-round participation in sports, that is, those either not participating in sports or doing so for at least 9 months per year, a significant association between %BF and physical activity was shown without taking seasonality into account. This association was not observed when the analysis was repeated for the remaining men, that is, those participating in sports but for less than 9 months per year. These results suggest that %BF was only negatively associated with physical activity in participants with a consistent year-round participation in sports. In other words, a variable year-round degree of physical activity obscures the association between %BF and physical activity.

As described earlier, the discrepancy between genders in the association between body composition and physical activity-related energy expenditure shown in previous studies was concluded to result from an increased energy intake to compensate for a higher energy expenditure in women compared with men.[18] Given that in young women, no compensation in energy intake was shown in response to an increase in energy expenditure,[20] we hypothesized an age effect for this compensatory mechanism. This hypothesis is affirmed by the association between body composition and physical activity shown in the present study.

In conclusion, evidence was found for a negative association between %BF and physical activity in both men and women. A consistent year-round degree of physical activity appears to be a prerequisite to reveal the association. Finally, Tracmor-assessed physical activity improves the estimate of %BF when a participant's characteristics are taken into account.

Acknowledgements

We thank Loek Wouters for analyzing the deuterium samples.

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