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ORIGINAL REPORT

DIFFERENCES IN FAT LOSS IN RESPONSE TO PHYSICAL ACTIVITY AMONG SEVERELY OBESE MEN AND WOMEN

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Background: **Direct measurement of physical activity may be critical to revealing its relationship with the change in fat mass over time. The aim of this study was to determine the relationship between accelerometer-determined change in physical activity and change in fat mass in severely obese men and women.**

Methods: **A total of 49 severely obese men ($n=12$) and women ($n=37$) (mean age 42.8 years (standard deviation (SD) 9.6); mean body mass index 42.0 kg/m^2 (SD 5.9) participated in a 1-year lifestyle intervention with 4 measurements of physical activity (Actigraph GT1M accelerometer), energy intake (180-item food frequency questionnaire), and body composition. Associations were determined using linear regression analyses.**

Results: **In the total group change in both duration and intensity of physical activity were independently related to change in fat mass (partial $r=-0.38$ to -0.31, $p=0.001$–0.007) after adjustment for baseline body weight, gender and change in energy intake. A gender-specific effect of change in physical activity duration was found for change in fat mass (p for change in physical activity duration*gender <0.001), where the association was significant in men (partial $r=-0.53$, $p<0.001$), but not in women (partial $r=-0.17$, $p=0.149$).**

Conclusion: **Increased intensity of physical activity was associated with loss of fat mass in severely obese men and women, whereas physical activity duration was associated with fat mass loss in men.**

Key words: exercise; accelerometer; obesity; intervention studies; gender; sex.

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INTRODUCTION

Physical activity (PA) is the most important means of increasing energy expenditure. However, very modest weight loss is generally found to result from increased PA level (1, 2). It is likely that lack of compliance with prescribed PA cause both variation at an individual level and underestimation of the effectiveness of PA as a weight loss therapy on a group level (3, 4). Thus, accurate measurement of PA is critical in order to separate the question of whether the intervention was implemented successfully from that of whether the change in PA affects body weight (BW). Owing to the great variability between self-reported and objectively measured PA (5), PA must be measured directly. Previous studies have shown stronger relationships with BW and fat mass (FM) loss by using objective measures of PA (6) compared with self-reported PA (7, 8).

Men frequently achieve greater BW and FM losses in response to lifestyle interventions than do women (9–12). The apparent violation of the energy balance equation in women led Gleim (13) to conclude that it is "not prudent to tell a woman that she will lose weight if she exercises", unless she "is committed to many hours of exercise per day". However, this conclusion might not apply unless the actual PA level in such interventions is clearly determined. Nevertheless, evidence for a gender-specific effect of PA duration is suggested by 2 previous studies using self-reported PA (11, 14). We therefore performed a 1-year lifestyle intervention study in severely obese subjects with 4 measurements of energy intake (EI) and accelerometer-determined PA. The main aim was to determine the correlation between changes in PA and changes in BW and FM. A secondary aim was to test for gender-specific effects. We hypothesized an association between PA and loss of BW and FM, and that PA would lead to greater reductions in these variables in men than in women.

PATIENTS AND METHODS

Subjects

A total of 49 severely obese subjects participated in a lifestyle intervention at the Red Cross Haugland Rehabilitation Center (RCHRC) in Norway between February 2010 and October 2011. Inclusion criteria were: age 18–60 years, and body mass index (BMI) ≥ 40 kg/m^2 with or without comorbidities, or ≥ 35 with comorbidities. Exclusion criteria were: pregnancy; heart disease; drug or alcohol abuse; previous bariatric surgery; and mental disorders or physical impairments that could reduce the subject's ability to comply with the programme. Written informed consent was obtained from each subject before inclusion in the study. The study met the standards of the Declaration of Helsinki and was approved by the Regional Committee for Medical Research Ethics.

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Intervention programme

The intervention consisted of 3 intermittent inpatient periods (the first was 6 weeks' duration; the second and third were 3 weeks' duration) over the course of 1 year. The time-line of the study was an inpatient period from baseline to 6 weeks, a home period of approximately 14 weeks, an inpatient period from week 20 to 23, a home period of approximately 27 weeks, and an inpatient period from week 50 to 53.

An interdisciplinary team of health professionals (dietician, nurse, physician, physiotherapist and exercise specialist) was responsible for the programme at RCHRC, which had 3 main components: diet, PA and cognitive behaviour therapy. Regarding cognitive behaviour therapy, subjects participated in weekly group-sessions targeting how to take control over their eating (minimize use of food for purposes other than nutrition) and cope with barriers to PA in various situations. In addition, individual sessions were offered if needed. Regarding PA and diet, both theoretical and practical sessions were incorporated. The main goal regarding diet was to introduce a healthy diet and eating pattern to provide each subject with tools to improve the quality of their diet in the long-term. Thus, each subject followed a high-fibre, low-fat, reduced-energy meal plan based on the Nordic Nutrition Recommendations (15), which included 3 main meals and 2–3 snacks each day. Some meals were served, others were prepared by the subjects during group lessons on how to prepare healthy meals. As such, no specific diet, meal replacements or severe energy-restriction was applied.

Regarding PA, subjects participated in a supervised and structured exercise programme consisting of 20–30 min brisk walking before breakfast and 2 × 45–60-min exercise sessions (e.g. swimming, walking, aerobics, dancing, ball games or strength training) performed individually or in groups 5 days per week at the RCHRC. Occasionally (approximately once a week), subjects performed a 1–2 h scheduled hike. All exercise sessions were led by a physiotherapist and/or an exercise specialist. No specific target regarding intensity was specified; however, intensity varied from moderate (continuous swimming or walking) to high (interval training or ball games). In addition, subjects were encouraged to perform PA on their own during the inpatient periods. Together with a team member, each subject developed a plan for PA to be performed at home, adjusted to the subject's home situation and based on each subject's opportunities and preferences. A standard programme was omitted during the periods at home, as the main goal of this plan was to develop a programme that would be sustainable in the long-term relative to each subject's physical capacity, overall heath and context of living. The subjects were not offered any systematic follow-up at home, but they could contact the RCHRC or their general practitioner if needed. Thus, neither supervised exercise, nor any standard exercise programme was performed between the in-patient periods.

Procedures

BW and FM were measured every 3 weeks during the inpatient periods, which yielded a total of 7 measurements (baseline and weeks 3, 6, 20, 23, 50 and 53). PA level and diet were measured at 4 time-points. The first measurement was taken 1 month prior to the first inpatient period (baseline); the second was obtained during the first inpatient period (week 4/6), and the 2 last measurements were performed at home approximately 1 month before inpatient periods number 2 (week 16) and 3 (week 46), respectively.

BW and body composition were measured with subjects in the fasted state in light clothes in the morning after voiding. Both measures were reported to the nearest 0.1 kg using bioelectrical impedance analysis (BC 420 S MA, Tanita Corp, Tokyo, Japan). Notably, Tanita instruments provide valid estimates of changes in FM in obese subjects when compared with criterion-measured total body water (16, 17). In the present study the reliability of the FM measurements was assessed by performing measurements over 5 consecutive days in 15 subjects. A standard error of 0.47 kg was found.

PA was measured using an Actigraph GT1M accelerometer (Actigraph, Fort Walton Beach, FL, USA) and analysed with the ActiLife software v. 5.3. Subjects were instructed to wear the accelerometer over a 7-day period, except during water activities or while sleeping. The accelerometer was attached in the mid-axillary line of the right hip at the height of the umbilicus. A wear-time of ≥ 10 h/day for ≥ 4 days was used as the criterion for a valid measure, whereas periods of ≥ 60 min (allowing for ≤ 2 min of non-zero counts) were defined as non-wear time (18, 19). PA was reported as PA duration and PA intensity. Duration of PA was reported as minutes of moderate to vigorous PA per day (MVPA/day) (≥ 3 metabolic equivalents (METs)) using a previously defined cut-point of ≥ 852 counts/min in these severely obese subjects (20). The applied cut-point is slightly higher than that reported previously owing to the application of a slightly different model. The combined measure of MVPA/day was used because very few subjects were found to perform vigorous PA (≥ 6 METs; ≥ 5,200 counts/min). Self-reported duration of swimming, bicycling and resistance training were added to the accelerometer-determined minutes of MVPA/day, because these modes of activity are poorly captured by the accelerometer and comprised a large part of the programme at RCHRC.

Intensity of PA was reported as the mean counts/min in bouts of MVPA. The time spent in bouts of MVPA was defined as consecutive time in MVPA of ≥ 10 min in duration allowing for a decrease of ≤ 2 min below the cut-point. Diet was assessed using a validated 180-item food frequency questionnaire (21). Subjects were asked to report the average diet consumed over the last year at baseline, to report the diet over the last month for measurement number 2 and to report the diet over the last 3 months for measurements number 3–4. The questionnaires were analysed through computer scanning and manually checked for any items added at the Department of Nutrition, The University of Oslo, Norway.

Statistical analysis

The data on PA duration, PA intensity, EI, BW, FM and lean mass (LM) are presented as the mean values (standard deviation (SD)). The independent samples *t*-test was used to test for baseline differences between the genders, and the Man-Whitney test was used for comparing the groups on percentage PA assessed by self-report and in the attrition analyses.

A linear mixed model based on restricted maximum likelihood estimation was used in all analyses for changes (Δ) over time. Distribution of observations was verified for each variable prior to analysis. Actual values were used to analyse changes over time in the combined group of men and women (observations were normally distributed). *Post-hoc* analyses were performed using the Sidak *post-hoc* test comparing all time-points with baseline. Differences between genders were tested using the ranks of the Δ-scores from baseline (because data were skewed within each gender group) by including time and gender in the model.

The association between ΔPA duration, ΔPA intensity and ΔEI (independent variables) and ΔBW, ΔFM and ΔLM (dependent variables) were analysed using Δ-scores between time-points ($\Delta y_1 = y_2 – y_1$; $\Delta x_1 = x_2 – x_1$, etc.) (22). The standard repeated linear mixed model using actual values was omitted because the interpretation of the regression coefficients in such a model is difficult, owing to the mixing of longitudinal (within-subject) changes and the cross-sectional (between-subject) differences (22). Six regression models were run for each outcome variable: models 1–3 tested the bivariate relationships; model 4 contained ΔPA duration, ΔPA intensity and ΔEI; model 5 was similar to model 4, but also included gender and baseline BW; in model 6 we added interactions between ΔPA duration, ΔPA intensity, ΔEI and gender (ΔPA duration*gender; ΔPA intensity*gender; ΔEI*gender) to model 5. To determine gender-specific associations the gender variable were re-coded (0 and 1 vs 1 and 0 for men and women, respectively) and the analyses repeated. Residuals were normally distributed in all models and no variables were collinear. The figure shows ΔPA duration vs residual ΔFM based on model 6, after exclusion of PA duration and insignificant interactions.

For body composition the differences between the measurements at baseline and week 6 (Δ1), between week 6 and week 20 (Δ2) and between week 20 and week 50 (Δ3) were used in the analyses of as-

Table I. *Subject characteristics*

	Total (n=49) Mean (SD) [n]	Men (n=12) Mean (SD) [n]	Women (n=37) Mean (SD) [n]	p-value for gender differences
Age	42.8 (9.6)	42.3 (8.2)	43.5 (10.1)	0.843
Height, cm	171.9 (9.2)	183.2 (8.2)	168.3 (6.0)	<0.001
Weight, kg	123.9 (18.6)	135.2 (16.5)	120.2 (18.0)	0.014
WC, cm	128.3 (13.0)	131.6 (10.8)	127.2 (13.6)	0.321
BMI, kg/m^2	42.0 (5.9)	40.4 (5.4)	42.5 (6.1)	0.305
Fat mass, kg	58.2 (11.7)	51.7 (9.4)	60.3 (11.7)	0.026
Lean mass, kg	65.5 (13.0)	83.5 (10.2)	59.8 (7.4)	<0.001
VO_{2max}, l/min	3.28 (0.71) [37]	4.22 (0.59) [9]	2.97 (0.41) [28]	<0.001
VO_{2max}, ml/kg/min	27.4 (5.4) [37]	32.7 (5.2) [9]	25.6 (4.3) [28]	<0.001

WC: waist circumference; BMI: body mass index; VO_{2max}: maximal oxygen consumption; SD: standard deviation.

sociations (4 time-points). Because time-points were unequally spaced, ΔBW, ΔFM and ΔLM were scaled to changes per week to render the regression coefficients meaningful.

All analyses were performed using SPSS version 19.0 (SPSS Inc., Chicago, USA). A p-value ≤0.05 indicated statistically significant findings.

RESULTS

Subject characteristics and attrition analysis

The characteristics of the subjects are shown in Table I. Eleven subjects (4 men and 7 women) were lost to follow-up during the intervention; 1 due to pregnancy, 4 dropped out of the programme (1 underwent bariatric surgery; 1 having reached his weight goal, and 2 for unknown reasons); 6 withdrew from the study (4 having problems with the study protocol and 2 for unknown reasons). In addition, a total of 16 observations of PA were excluded due to a failure to fulfil the validity criteria (2, 4, 5 and 5 at baseline, weeks 4, 16 and 46, respectively). Final sample sizes at each time-point are shown in Tables II and III. The subjects lost to follow-up were heavier (median 140.5 kg, 95% confidence interval (CI) 118.1–145.6 vs median 116.7 kg, 95% CI 113.5–124.2, p=0.042) and exhibited reduced PA durations (median 74.9, 95% CI 33.0–92.7 vs median 98.3, 95% CI 89.6–108.0 min of MVPA/day, p=0.045) compared with the study sample. The early responses (changes observed to the 6-week time-point) did not differ between the groups (p=0.071–0.734).

Changes in physical activity level and energy intake

The duration of PA increased by 74.8% from baseline to 6 weeks (p<0.001) (Table II). Changes did not differ from baseline at week 16 (5.8% increase, p=0.782) or week 46 (15.6% increase, p=0.215). Men increased their PA duration more than women (93.5%, 50.0% and 48.7% increases from baseline to weeks 6, 16 and 46, respectively, in men vs corresponding numbers in women of 73.7%, 2.2% and 1.8%, p=0.032). The intensity of PA increased by 22.8% (p<0.001) from baseline to week 4 and remained increased (22.5%, p=0.001) at week 16. The change at week 46 was not different from baseline values (4.1% increase, p=0.147). There were no gender difference (p=0.709). At baseline and weeks 16 and 46, median duration of MVPA from self-report were 0.0–7.3% of total MVPA. The corresponding number at week 4 was 25.8%. The numbers were similar between genders (p>0.108).

EI was significantly decreased both at 6 weeks (15.9%, p=0.002) and 16 weeks (16.8%, p=0.016), whereas the change at week 46 (15.0% decrease) was not significant (p=0.097). The changes in EI were similar in men and women (p=0.291).

Table II. *Change in duration and intensity of physical activity (PA) and energy intake (EI) during the 1-year intervention*

	Baseline Mean (SD)	Week 4/6 Mean (SD)	Week 16 Mean (SD)	Week 46 Mean (SD)	p-value for effect of time
PA duration	94.2 (42.5)	164.7 (31.4)**	99.7 (33.0)	108.9 (38.3)	<0.001
Men	75.2 (37.8)	161.0 (28.7)	107.7 (34.9)	113.4 (30.6)	
Women	100.1 (42.7)	166.0 (32.6)	97.0 (32.5)	107.6 (40.9)	
PA intensity	2,389 (742)	2,935 (738)**	2,870 (1018)**	2,620 (828)	<0.001
Men	2,829 (1168)	3,303 (676)	3,260 (1484)	2,803 (682)	
Women	2,286 (586)	2,809 (726)	2,736 (794)	2,564 (873)	
EI	11.3 (4.3)	8.9 (2.7)**	9.1 (2.9)*	9.7 (3.0)	0.006
Men	11.1 (4.2)	9.5 (3.2)	9.8 (3.6)	9.6 (3.5)	
Women	11.3 (4.4)	8.7 (2.6)	8.7 (2.6)	9.7 (2.9)	

*p<0.05; **p<0.01.

Units are minutes of MVPA/day for PA duration, counts/min in bouts of MVPA for PA intensity and counts/min for total PA level; PA: physical activity; MVPA: moderate to vigorous physical activity; n for PA: total (men)=42 (10), 43 (11), 36 (9) and 30 (7) at baseline, weeks 4, 16 and 46, respectively; n for EI: total (men)=40 (9), 47 (12), 37 (11) and 34 (8) at baseline, weeks 4, 16 and 46, respectively.

SD: standard deviation.

Table III. *Change in body weight, fat mass and lean mass during the 1-year intervention*

	Baseline Mean (SD)	Week 3 Mean (SD)	Week 6 Mean (SD)	Week 20 Mean (SD)	Week 23 Mean (SD)	Week 50 Mean (SD)	Week 53 Mean (SD)	*p* for change over time
Body weight, kg	123.9 (18.6)	120.2 (17.7)**	117.7 (17.5)**	113.1 (17.9)**	111.4 (17.9)**	114.6 (18.4)**	112.5 (18.1)**	<0.001
Men	135.2 (16.5)	131.1 (15.7)	128.1 (15.9)	123.1 (16.4)	122.3 (16.9)	125.6 (15.0)	122.8 (15.4)	
Women	120.2 (18.0)	116.6 (17.0)	114.2 (16.8)	110.1 (17.5)	108.2 (17.1)	110.8 (18.2)	109.0 (17.9)	
Fat mass, kg	58.2 (11.7)	55.3 (12.4)**	53.0 (12.5)**	51.0 (12.1)**	49.5 (12.3)**	51.2 (11.9)**	50.0 (12.6)**	<0.001
Men	51.7 (9.4)	47.6 (10.7)	44.6 (11.5)	44.2 (11.2)	41.9 (11.2)	45.5 (7.9)	43.4 (11.2)	
Women	60.3 (11.7))	57.9 (11.9)	55.8 (11.7)	53.1 (11.8)	51.8 (11.8)	53.1 (12.5)	52.3 (12.5)	
Lean mass, kg	65.6 (13.0	64.9 (12.7)	64.7 (12.9)	62.1 (11.4)**	61.9 (12.1)**	63.4 (12.3)	62.5 (11.9)*	<0.001
Men	83.5 (10.2)	83.4 (8.6)	83.5 (8.4)	78.9 (7.1)	80.4 (7.8)	80.1 (9.2)	79.5 (7.1)	
Women	59.8 (7.4)	58.7 (6.0)	58.4 (6.1)	57.1 (6.5)	56.3 (6.1)	57.6 (6.7)	56.7 (6.2)	

*$p<0.05$; **$p<0.01$ compared with baseline.
Total n (men) = 49 (11), 48 (11), 48 (11), 43 (10), 43, (10), 35 (9) and 35 (9) at baseline, and weeks 3, 6, 20, 23, 50 and 53, respectively.
SD: standard deviation.

Changes in body weight and body composition

BW and FM decreased over time, and all time-points were significantly different from baseline ($p<0.001$) (Table III). Men lost more weight ($p=0.015$) and FM ($p=0.029$) than women. Change in LM was only different from baseline at weeks 20 and 23 ($p=0.001$) and week 53 ($p=0.026$) and was similar in men and women ($p=0.182$).

Associations between changes in physical activity, energy intake and body composition

Associations between behaviour changes and body composition are shown in Table IV. Changes in PA duration, PA intensity and EI were significantly related to ΔBW and ΔFM in the bivariate analyses. Whereas ΔPA duration and ΔPA intensity remained significantly related to ΔBW and ΔFM in the multivariable model (model 5), ΔEI was no longer related to ΔFM or ΔBW ($p>0.080$). We found significant interactions (model 6) between gender and ΔPA duration for ΔFM (Fig. 1) and ΔLM (differences in slopes (women vs men) were 0.0064 (95% CI 0.0029–0.0098) kg/min MVPA/week for ΔFM and –0.0035 (95% CI –0.0062 to –0.0008) kg/min MVPA/week for ΔLM). The relationships between PA duration and ΔFM (partial $r=-0.53$, $p<0.001$) and ΔLM (partial $r=0.31$, $p=0.010$) were significant in men, but not in women (ΔFM: partial $r=-0.17$, $p=0.149$; ΔLM: partial $r=0.08$, $p=0.524$).

DISCUSSION

There are 3 main findings from this study. First, PA showed a dose–response relationship with change in BW and FM in severely obese subjects. Secondly, PA duration induced a gender-specific effect on FM; men had greater losses for every minute of change in MVPA compared with women. Thirdly, whereas the men increased their free-living PA duration, women did not.

Table IV. *Associations (partial r) between change in behaviour (ΔPA and ΔEI) and body composition (ΔBW, ΔFM and ΔLM)*

		BW		FM		LM	
Model	Covariate	Partial r	(*p*)	Partial r	(*p*)	Partial r	(*p*)
1	ΔPA duration	–0.57	(<0.001)	–0.60	(<0.001)	0.05	(0.624)
2	ΔPA intensity	–0.38	(<0.001)	–0.35	(0.001)	–0.03	(0.793)
3	ΔEI	0.37	(<0.001)	0.35	(<0.001)	0.06	(0.548)
4	ΔPA duration	–0.34	(0.003)	–0.39	(0.001)	0.08	(0.522)
	ΔPA intensity	–0.29	(0.012)	–0.32	(0.005)	0.04	(0.736)
	ΔEI	0.23	(0.052)	0.16	(0.174)	0.10	(0.419)
5	Gender	–0.02	(0.873)	0.05	(0.701)	–0.08	(0.478)
	BW	–0.07	(0.536)	0.03	(0.811)	–0.13	(0.261)
	ΔPA duration	–0.34	(0.003)	–0.38	(0.001)	0.06	(0.589)
	ΔPA intensity	–0.29	(0.013)	–0.31	(0.007)	0.03	(0.826)
	ΔEI	0.21	(0.080)	0.17	(0.164)	0.06	(0.610)
6	Gender	–0.01	(0.954)	0.04	(0.720)	–0.07	(0.592)
	BW	–0.07	(0.557)	0.06	(0.599)	–0.18	(0.138)
	ΔPA duration	–0.32	(0.007)	–0.53	(<0.001)	0.31	(0.010)
	ΔPA intensity	–0.17	(0.158)	–0.21	(0.087)	0.02	(0.827)
	ΔEI	–0.01	(0.928)	0.11	(0.358)	–0.16	(0.196)
	ΔPA duration*gender	0.18	(0.136)	0.41	(<0.001)	–0.30	(0.011)
	ΔPA intensity*gender	–0.07	(0.591)	–0.04	(0.730)	–0.04	(0.755)
	ΔEI*gender	0.09	(0.443)	–0.02	(0.866)	0.16	(0.200)

Model 1–3 are bivariate; model 4 includes all behaviour changes; model 5 are adjusted for body weight and gender; model 6 adds interactions between gender and behaviour changes to model 5. Gender: 0 = men, 1 = women. $n=77$ observations.
PA: physical activity; EI: energy intake; BW: body weight; FM: fat mass; LM: lean mass.

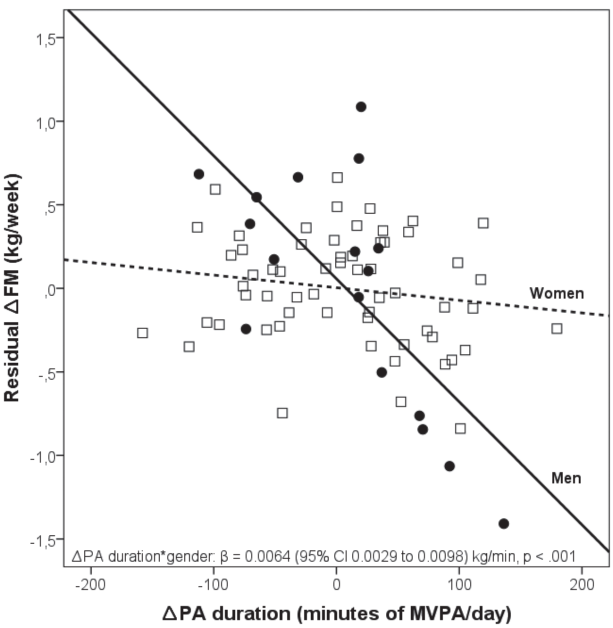

Fig. 1. Scatter-plot showing the relationship between the change in physical activity (PA) duration and change in residual fat mass (FM) in men and women after adjustment for gender, body weight, change in PA intensity, and change in energy intake. Solid circles and *solid line*=men; *open squares and dotted line*=women. Number of observations=77. MVPA: moderate to vigorous PA; 95% CI: 95% confidence interval.

Although lifestyle interventions have been shown to lead to weight reduction in severely obese subjects (9, 14, 23, 24), there are few reports on the relationship between PA and weight reduction (14, 23). Although bariatric surgery is an effective weight-loss modality, the present study shows that severely obese subjects have the potential to lose weight if behaviour changes are incorporated, and demonstrates that a lifestyle intervention can be a viable option for some patients. Moreover, there is irrefutable evidence of the effectiveness of regular PA in the primary and secondary prevention of a range of chronic diseases, as well as premature death (25).

To the best of our knowledge, we are the first to present results showing a gender-specific FM change in response to change in PA duration using an objective measure of PA. However, two previous studies have shown similar results using self-reported PA (11, 14). Hollis et al. (11) demonstrated a significant interaction between gender and PA duration in the prediction of BW change in a large multicentre randomized controlled trial (n=1,685) with a 6-month follow-up period. Furthermore, we have recently shown similar results in another small sample of severely obese subjects undergoing lifestyle treatment at RCHRC (14). In that study, the duration of PA, recorded with training diaries, explained 55.8% and 5.6% of BW loss for men and women, respectively. Thus, a gender-specific effect of PA duration seems to be a consistent finding in this severely obese population, as findings are similar whether PA is measured by self-report or by accelerometry.

Several hypotheses have been proposed to explain the greater weight loss response to PA in men compared with women (13, 26). First, an obvious cause is that men, because of their greater BW, spend more energy for every minute of PA than women. Evidence from the Midwest Exercise Trial suggests that differences found between genders when exercise is prescribed in terms of PA duration (10), disappears when men and women are matched on energy expenditure (27). However, we found a highly significant gender-specific effect of PA duration after adjustment for both BW and ΔPA intensity (i.e. given an equal BW and PA intensity in both gender groups). Thus, the present results suggest that PA duration might affect FM differently for men and women beyond differences in PA energy expenditure.

Secondly, fat distribution differs between men and women (28) and gender-specific fat distribution and fat tissue characteristics may explain the findings. Greater intra-abdominal FM in conjunction with a possibly greater adrenergic response to PA (29) in men may favour FM loss in men compared with women. Similarly, Kuk & Ross (30) showed that men lost more intra-abdominal fat and that women lost more lower-body subcutaneous fat for a given BW loss; however, total fat losses was similar between genders.

Thirdly, clustering or interaction between a host of factors may make weight loss extremely difficult for some individuals (26), especially women, as indicated by their more restrictive energy conservation (31, 32). In response to PA, women have been shown to compensate by increasing the EI corresponding to approximately 33% of the PA energy expenditure in the short-term, whereas no compensation is seen in men (31, 32). However, this is unlikely to explain our findings, as we adjusted for ΔEI during the intervention.

Fourthly, the gender-differences in slope for ΔFM could be due to an impaired within-subject precision of the body composition measurements in women over time, for example due to the menstrual cycle, which we did not assess. Alternatively, the clear gender-specific effect found using ΔFM vs ΔBW shows the importance of measuring body composition in weight loss trials, and confirms bioelectrical impedance analysis as a valid measurement tool.

We have no explanation for the interaction effect for ΔLM. It could be that men performed more strength training than women, as strength training can conserve LM in weight loss trials (33). However, few subjects performed resistance training, and we could not find any evidence for a gender difference. This is in line with a previous study at RCHRC (14).

In both genders there were increases in PA during the first in-patient period, but this level of PA seemed difficult for subjects to maintain at home, especially for women. This might be expected because simple behaviour change might be quite easily achieved outside one's normal context of living and away from daily obligations, compared with the complex task of changing one's way of living in the home environment. Close follow-up in the long term, e.g. weekly or biweekly contact during the periods at home (34), would probably be important to maintain an active lifestyle throughout the intervention.

It is well known that compliance with lifestyle interventions varies, which points to a crucial aspect regarding the reporting of such study results. We argue that measuring the actual behaviour changes is of critical importance to accurately identify which question one is answering; one of effectiveness or efficacy (35). The present study answered both questions; in terms of PA the implementation of the intervention was very moderately successful (the intervention had moderate effectiveness); however, PA proved to be important in terms of BW and FM loss (the efficacy of PA to promote weight loss was modest to good), at least in men. This is an important distinction that could potentially clarify some of the "mysterious" weight loss outcomes in response to lifestyle interventions.

Strengths and limitations

The present study has two main strengths. First, changes in PA were measured objectively using an accelerometer. Due to the highly inconsistent relationships found between self-reported and objectively measured PA (5), we believe that this is an important improvement over many previous weight-loss studies. Secondly, the behaviour changes were measured at multiple time-points during the 1-year intervention, showing the patterns of change over time. This allowed us to explore the effectiveness and efficacy of the intervention (35).

An important limitation of the present study was the relatively small sample size and the fact that men comprised only approximately a quarter of the sample, which limited the power to detect interactions and the ability to perform statistical analysis within each gender group. Although we detected significant gender-interactions (ΔPA duration*gender) for ΔFM and ΔLM, inclusion of a larger and balanced sample could leave alternative results. Secondly, EI was assessed by self-report and might be flawed by measurement error (36, 37). The results indicated that EI was under-reported in both genders (results not shown), as expected (36). Although the reporting bias might be relatively stable over time (38) (i.e. leaving valid observations for changes over time), an increased underestimation over time might be promoted by the ongoing intervention due to increased social desirability (37). Thirdly, accelerometers have certain limitations. Importantly, they do not capture some commonly performed modes of PA, such as swimming, bicycling or strength training. Therefore, measurements of PA were corrected for self-reported duration of these modes of activity. Moreover, the attachment of the accelerometers can be challenging for severely obese subjects, and tilting of the instrument is known to reduce the level of counts (39). Together with great variability in gait patterns between subjects, greater measurement variability may be expected in this population than would have been found in other populations. Finally, our results are based on associations and are vulnerable for residual confounding. Thus, causality may not be inferred from our findings.

Further research

Further research is needed to target possible differences between genders in the weight loss field, as previously recommended by others (40), as this might facilitate the development of tailored lifestyle intervention programmes. Furthermore, we recommend the objective measurement of PA level in weight loss trials. Finally, research should target strategies to implement and maintain behaviour changes in free-living obese subjects.

Conclusion

We found that increased duration and intensity of PA were associated with BW and FM loss in severely obese men and women undergoing a 1-year lifestyle intervention. Thus, we conclude that PA can improve weight status, if actually carried out. However, increased PA duration induced greater FM loss in the men compared with the women. Although this finding must be interpreted with caution due to the small sample size, it indicates that men may have a higher probability of succeeding in lifestyle interventions for obesity.

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