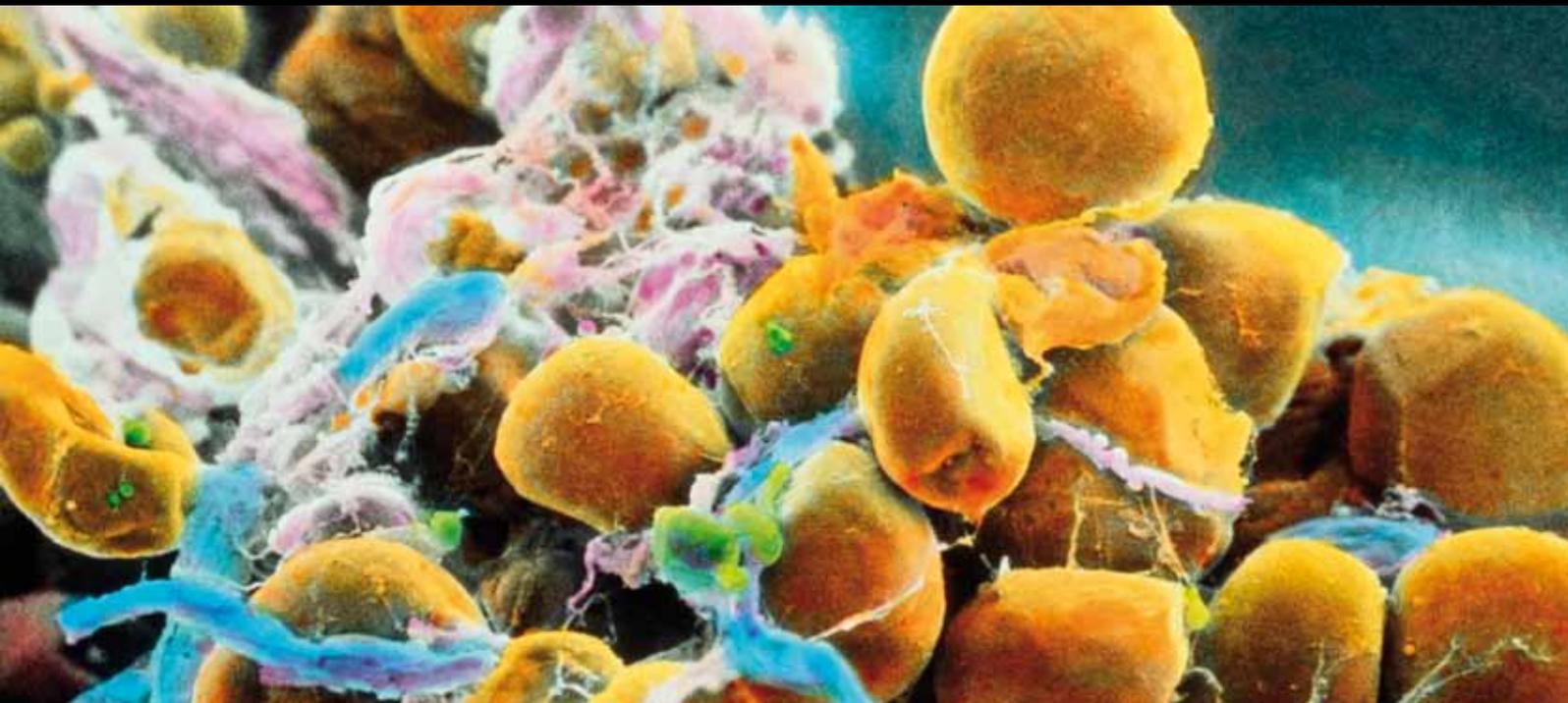


# UPDATE ON EXERCISE AND WEIGHT CONTROL

GUEST EDITORS: ÉRIC DOUCET, NEIL KING, JAMES A. LEVINE, AND ROBERT ROSS





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## **Update on Exercise and Weight Control**

Journal of Obesity

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Guest Editors: Éric Doucet, Neil King, James A. Levine,  
and Robert Ross



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## Editorial

# Update on Exercise and Weight Control

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Recent analyses of population data reveal that obesity rates continue to rise and are projected to reach unprecedented levels over the next decade [1]. Despite concerted efforts to impede obesity progression, as of today, weight loss and weight maintenance strategies remain at best partially successful endeavours. Regardless of the observation that weight loss strategies can produce significant weight loss [2] and substantial improvements of the determinants of the metabolic risk profile [3, 4], it is clear that actual weight loss tends to be lower than the anticipated weight loss, and most individuals who achieve weight loss will likely regain some weight [5] and even overshoot [6] their preintervention body weight. As such, an improved understanding of the factors that contribute to lower than expected weight loss and poor weight maintenance would improve the effectiveness of weight loss interventions.

Increasing physical activity participation is frequently recommended as a method of improving weight management for its recognized ability to positively impact metabolic [7] and psychological health [8–10]. Despite these valuable outcomes, weight loss is often much less than expected, when exercise is employed as the sole means of intervention [11] at least as far as effectiveness is concerned. This suggests that, amongst other things, compensatory responses (i.e., increased energy intake and/or reduced nonstructured physical activity) occur which undermine the weight loss. It is possible that these compensatory responses are driven at least in part by the observations that weight loss and exercise increase appetite and the reinforcing value of foods [12, 13]

and that exercise has also been shown to decrease nonexercise energy expenditure [14]. Exercise can also lead to beneficial changes in ectopic fat storage even in the absence of major changes in body weight [15], an outcome that may be easily overlooked with traditional markers of weight loss success.

In this special issue we sought papers related to exercise-induced weight loss with a particular emphasis on the effects of exercise on ectopic fat mobilization, non-exercise activity thermogenesis, and appetite regulation. This special issue contains 14 original manuscripts and 5 review articles that cover a wide array of methodologies, populations, training modalities but that all share the common feature of dealing with different aspects of physical activity/exercise and weight management.

Five comprehensive reviews appear in this special issue. In the paper by B. Strasser and W. Schobersberger “*Evidence for resistance training as a treatment therapy in obesity*”, clear recommendations on the use of resistance training for the treatment of obesity were derived from available literature. J. Nantel et al. present in “*Physical activity and obesity: biomechanical and physiological key concepts*” an interesting overview of the biomechanical considerations related to physical activity and obesity whereas the paper by S. H. Boutcher “*High-intensity intermittent exercise and fat loss*” provides arguments for increasing exercise intensity to improve the effects of exercise on fat mobilization and metabolic health. The fourth review article by J. P. Chaput et al. “*Physical activity plays an important role in body weight regulation*” presents a series of studies that provide evidence

in support of an important role of physical activity in body weight control. In the last of the reviews “*Cognitive-behavioral strategies to increase the adherence to exercise in the management of obesity*”, R. D. Grave et al. surveyed the literature on cognitive-behavioural strategies to increase the adherence to exercise in hopes of improving weight management.

The special issue included three original research communications that dealt directly with eating behaviour and appetite. Results presented in “*Low fat loss response after medium-term supervised exercise in obese is associated with exercise-induced increase in food reward*” by G. Finlayson et al. highlight the role of hedonic processes and, in particular, increased food reward as a contributor to reduced fat loss in response to exercise. The paper “*Influence of physical activity participation on the associations between eating behaviour traits and body mass index in healthy postmenopausal women*” by M. E. Riou et al. presents evidence that the relationship between eating behaviour traits and adiposity may well be modulated by the level of physical activity. In the third paper “*The acute effects of swimming on appetite, food intake, and plasma acylated ghrelin*,” J. A. King et al. report that moderate intensity swimming increases appetite, but that this effect is not related to circulating ghrelin levels.

Two additional research communications are directly in line with this special issue. The first one “*Acute impact of moderate-intensity and vigorous-intensity exercise bouts on daily physical activity energy expenditure in postmenopausal women*” presents results that support the notion that total physical activity energy expenditure may actually be lower on days where structured exercise is performed in obese women, an effect that seems to be accentuated for high intensity exercise. Results in “*Impact of weight loss on physical function with changes in strength, muscle mass, and muscle fat infiltration in overweight to moderately obese older adults: a randomized clinical trial*” from an exercise intervention with or without a weight loss component showed that muscle fat infiltration decreased significantly in both groups but to a much greater extent in the exercisers that also experienced weight loss.

This special issue also contains 4 original research communications that relate the effects of exercise and weight control on psychological outcomes. In the paper “*Predictors of psychological well-being during behavioral obesity treatment in women*” by P. N. Vieira et al., the results support that self-determined motivation for exercise seems to positively impact some psychological variables, an effect that is independent of weight change during the weight loss intervention. Amongst other things, the paper “*Behavioral and psychological factors associated with 12-month weight change in a physical activity trial*” by M. A. Napolitano and S. Hayes highlighted that the success of long-term weight loss was related to improved self-efficacy whereas weight gain was associated to depressed mood. Results by A. J. Green et al. paper “*Impact of regular exercise and attempted weight loss on quality of life among adults with and without type 2 diabetes mellitus*” published in this issue show that exercise does not exert the same effects on quality of life in individuals with type 2 diabetes. The last paper in this

group “*Effectiveness of a home-based postal and telephone physical activity and nutrition pilot program for seniors*” investigated the effects of a 12-week home-based physical activity and nutrition intervention in seniors. The program was successful at increasing walking time which was partly attributable to increased awareness of health and well-being.

Three original papers related to children appear in this special issue. In one of these papers “*Utility of accelerometers to measure physical activity in children attending an obesity treatment intervention*” reported, W. Robertson tested the utility of accelerometers to assess physical activity in children attending an obesity treatment intervention. The results highlight the possibility that accelerometers may underestimate physical activity in this population. Results from another study reported in the paper “*How children move: activity pattern characteristics in lean and obese chinese children*” different physical activity patterns measured with accelerometry between lean and obese children in the paper. “*A 10-month physical activity intervention improves body composition in young black boys*,” an after-school physical activity program was shown to improve body composition and fitness in African-American boys who attended at least 3 times per week.

The last two communications relate to levels of physical activity. In the first of these 2 papers “*SALSA: sAVING lives staying active to promote physical activity and healthy eating*,” an 8-week Latin dance intervention was shown to increase physical activity in overweight women. Results of the last study in this issue “*Population-based estimates of physical activity for adults with type 2 diabetes: a cautionary tale of potential confounding by weight status*” suggest that estimates of physical activity levels vary by BMI categories, which may lead to misclassify adults with type 2 diabetes as being sufficiently active.

In summary, the original research combined with the review papers in this special issue highlight the fact that research on exercise and body weight control is evolving. The breadth of research questions around this topic will, in time, help us understand the multifaceted aspects of the effects of exercise on the management of body weight and the complications associated with increased adiposity.

Éric Doucet  
Neil King  
James A. Levine  
Robert Ross

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## Review Article

# Evidence for Resistance Training as a Treatment Therapy in Obesity

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Over the last decade, investigators have paid increasing attention to the effects of resistance training (RT) on several metabolic syndrome variables. Evidence suggests that skeletal muscle is responsible for up to 40% of individuals' total body weight and may be influential in modifying metabolic risk factors via muscle mass development. Due to the metabolic consequences of reduced muscle mass, it is understood that normal aging and/or decreased physical activity may lead to a higher prevalence of metabolic disorders. The purpose of this review is to (1) evaluate the potential clinical effectiveness and biological mechanisms of RT in the treatment of obesity and (2) provide up-to-date evidence relating to the impact of RT in reducing major cardiovascular disease risk factors (including dyslipidaemia and type 2 diabetes). A further aim of this paper is to provide clinicians with recommendations for facilitating the use of RT as therapy in obesity and obesity-related metabolic disorders.

## 1. Introduction

The inclusion of resistance training (RT) as an integral part of an exercise therapy program has been endorsed by the American Heart Association [1], the American College of Sports Medicine [2], and the American Diabetes Association [3]. While these recommendations are primarily based on the effects of RT on muscle strength, cross-sectional studies have shown that muscle mass is inversely associated with all-cause mortality [4] and the prevalence of the metabolic syndrome [5], independent of cardiorespiratory fitness levels.

Aging is associated with a loss of both muscle mass and the metabolic quality of skeletal muscle. Sarcopenia, the loss of muscle mass associated with aging, is a main cause of muscle weakness in old age and leads consequently to an increased risk for development of obesity-associated insulin resistance and type 2 diabetes mellitus [6]. Research supports the use of RT to prevent an age-related decline in skeletal muscle mass (which is approximately 0.46 kg of muscle per annum from the fifth decade on). Strong evidence indicates that muscle maintains its plasticity and capacity

to hypertrophy, even into the 10th decade of life [7–9]. However, there is some evidence to suggest that muscle strength and its effect on body composition and metabolic risk factors may be more important than muscle mass [10]. Accordingly, the term of “dynapenia” to qualify the loss of muscle strength with normal aging has been proposed [11]. A number of neural factors may be implicated in the age-associated loss of muscle strength, but also alterations in contractile properties are discussed.

Skeletal muscle is the primary metabolic target organ for glucose and triglyceride disposal and is an important determinant of resting metabolic rate. The potential consequences of age-related reduction in skeletal muscle mass are diverse, including reduced muscle strength and power, reduced resting metabolic rate, reduced capacity for lipid oxidation, and increased abdominal adiposity. With increasing adiposity, the insulin-mediated glucose uptake in skeletal muscle of elderly patients is reduced [12]. Evidence suggests that the maintenance of a large muscle mass may reduce metabolic risk factors—namely, obesity, dyslipidaemia, and type 2 diabetes mellitus—associated with cardiovascular

disease [13–15]. Despite the fact that a high muscle mass is associated with a favourable metabolic profile, one study reported that a higher muscle mass can be associated with metabolic disturbances in obese women [16]. The possible mechanisms may include increased concentrations of free androgens due to diminished levels of SHBG, a protein-sparing effect due to increased lipid metabolism, and changes in muscle capillarization and fiber composition due to visceral adiposity.

For the most part, recommendations to treat or prevent overweight and obesity via physical activity have focused on aerobic endurance training (AET). Data suggest that RT may be an effective alternative for modifying metabolic risk factors. From this backdrop, the purpose of this review is to (1) evaluate the potential clinical effectiveness and biological mechanisms of RT in the treatment of obesity and (2) provide up-to-date evidence on the impact of RT in reducing cardiovascular disease (CVD) risk factors, namely, dyslipidaemia and type 2 diabetes.

## 2. Metabolic Effects of Resistance Training

**2.1. Weight Control.** Both resting and activity-related energy expenditure declines with age [17]; decreased energy expenditure can have a major adverse effect on weight maintenance [18]. Studies on the usefulness of RT in the context of weight loss have demonstrated mixed results. Although it is clear that AET is associated with much greater energy expenditure during the exercise session than RT, some studies have shown that regular RT is effective in promoting weight loss in obese persons [19, 20]. A significant number of studies have shown that RT is associated with a decrease in fat mass (FM) and a concomitant increase in lean body mass (LBM) and thus has little or no effective change in total body weight [21–27]. RT increased muscle mass by a minimum of 1 to 2 kg in studies of sufficient duration.

The implementation of RT within a dietary intake restriction programme has been studied, along with a combined dietary restriction and AET programme [28–32]. In terms of relative effects, the addition of RT has been found to prevent the loss of LBM, secondary to dietary restriction [33, 34]. One study demonstrated that twice-weekly RT could prevent age-associated loss of LBM, as well as associated resting metabolic rate (RMR) which is closely correlated to losses in LBM [35]. RT contributes to elevations of RMR as a result of a greater muscle protein turnover [36]. Theoretically, a gain of 1 kg in muscle mass should result in an RMR increase of approximately 21 kcal/kg of new muscle. Thus, RT, when sustained over years or decades, translates into clinically important differences in daily energy expenditure and age-associated fat gains. For example, a difference of 5 kg in LBM translates to a difference in energy expenditure of 100 kcal per day (equivalent to 4.7 kg FM per year) [37]. However, a number of studies have shown that RT will increase RMR, at least if the training is intense enough to induce an increase in LBM [38–40].

In a randomized control trial [41], 35 overweight men were randomized to either a control group, a diet-only

group, a diet group that performed AET, or a diet group that performed both AET and RT. After 12 weeks, the weight loss in the three intervention groups was similar and significant, of which 69%, 78%, and 97%, respectively, were accounted for by fat loss. This study highlights the potential for RT to provide a unique stimulus to spare catabolism of body protein, thus altering the relationship between the LBM and FM. Exercise provided no additional stimulus for greater weight loss compared with that obtained from dietary restriction alone. The diet-only group also demonstrated a significant reduction in LBM.

Another study randomly assigned 29 obese men to one of three 16-week treatments, which consisted of a hypocaloric diet alone or in combination with RT (at 80% of 1-RM) or AET [19]. Whereas reduction in weight (–12.4 kg) and total adipose tissue (–9.7 kg) were not significantly different between the three groups, LBM was only preserved after the exercise training (independent of the mode), compared with the diet-only group (–2.5 kg). The principal finding of this study was that dietary restriction combined with either AET or RT increased the influence of diet alone on insulin levels in obese men.

A further trial assessed whether increases in LBM and decreases in FM from 15 weeks of twice weekly supervised RT (at 80% of 1-RM) could be maintained over 6 months of unsupervised exercise [25]. Over the total 39 weeks of RT, the treatment group gained 0.89 kg more in LBM, lost 0.98 kg more in FM, and lost 1.63% more in percent body fat when compared to the control group. Findings demonstrated that twice weekly RT did not result in any significant weight loss, but potentially could prevent age-associated fat gains over a period of years. Cited as feasible, was the likelihood that the positive body composition changes associated with RT could be maintained in an unsupervised exercise program after completion of the supervised exercise regime.

In a more recent study [42], an 8-week regime of RT delivered 3 times weekly (at 60% of 1-RM) significantly changed participants' body mass (+0.58%), percentage of body fat (–13.05%), LBM (+5.05%), and FM (–12.11%) when compared to the control group. This study supported a relationship between RT and body mass index (BMI), demonstrated by an increase in BMI. Therefore, the use of BMI in ascribing CVD risk should be used with caution in those individuals with an increased LBM (as would be expected following RT).

More recently, the effects of a 6-month RT program (at 50% to 80% of 1-RM) were analysed in relation to exercise-induced oxidative stress and homocysteine and cholesterol in normal-weight and overweight older adults [43]. Oxidative stress is suggested to be a potential contributor in the early and advanced stages of CVD [44]. In the study, 49 older adults were stratified by BMI and randomly assigned to either a control nonexercise group or an RT group. Findings demonstrated that lipid hydroperoxides (PEROXs) and homocysteine levels were lower in both the overweight and normal weight RT groups compared with control groups. Change in muscle strength was associated with homocysteine at 6 months, whereas the change in PEROXs was associated with the change in body fat. This

study showed that RT reduces exercise-induced oxidative stress and homocysteine, regardless of adiposity. Such a result indicates that this protection can be afforded in an older, overweight/obese population as effectively as in healthy older adults, which might indicate protection against oxidative insults (i.e., ischemia). A potential mechanism for RT-induced reduction of oxidative stress could include contraction-induced antioxidant enzyme up-regulation [45].

**2.2. Visceral Adipose Tissue.** Adipose tissue is a major endocrine organ, secreting substances such as adiponectin, leptin, resistin, tumor necrosis factor  $\alpha$ , interleukin 6, and plasminogen activator inhibitor-1 that may play a critical role in the pathogenesis of the metabolic syndrome [46]. Excessive central obesity and especially visceral adipose tissue have been linked with the development of dyslipidaemia, hypertension, insulin resistance, type 2 diabetes, and CVD [8, 12]. A relative increase in body fat is linked with a decline in insulin sensitivity in both obese and elderly individuals [47, 48].

Several studies have demonstrated decreases in visceral adipose tissue after RT programs [24, 26–28, 49, 50]. Treuth et al. observed significant decreases in visceral fat in older men and women after 16 weeks of RT [26, 27]. In two studies, Ross et al. measured regional fat losses after 16 weeks of exercise combined with dietary interventions in middle-aged obese men [28, 49]. In their first study [49], tests of both diet plus AET and diet plus RT (at 70% to 80% of 1-RM) elicited similar losses of visceral fat, which were greater than losses of whole-body subcutaneous fat. In a follow-up study [28], they isolated the effects of AET and RT (at 70% to 80% of 1-RM) by comparing the responses to diet alone. All 3 groups lost significant amounts of total body fat, and all 3 groups experienced a significantly greater visceral fat loss compared with whole-body subcutaneous fat loss. The changes amounted to a 40% reduction in visceral fat in the diet plus RT group, 39% in the diet plus AET group, and a 32% reduction in the diet-only group. One study raised the possibility of gender specificity in visceral fat reduction response to RT [24]. Hunter et al. studied older women and men after 25 weeks of RT (at 65% to 80% of 1-RM). Results demonstrated that both genders significantly increased muscle mass and decreased whole-body fat mass. However, women also lost a significant amount of subcutaneous and visceral adipose tissue (–6% and –11%, resp.), whereas the men did not.

Although more research is needed to clarify these possible gender-specific responses, the overall available body of literature supports the use of RT, with or without AET, and with or without diet modification, as an effective intervention in the reduction of abdominal obesity. It seems that RT has the potential to reduce visceral fat deposits through both immediate effects (e.g., during weight loss or weight maintenance) and delayed effects (during weight regain). The results of the two Ross et al. studies [28, 49] suggest a potential for low volume, high-intensity RT to achieve reductions in total and regional adipose tissue when

used in conjunction with a calorie-restriction diet. However, this observation requires confirmation by additional studies.

Overall, strong evidence supports the notion that regular RT can effectively alter body composition in obese men and women, independently from dietary restriction. It has been shown that RT increases LBM, muscular strength, and resting metabolic rate, and mobilizes the visceral and subcutaneous adipose tissue in the abdominal region. Further, RT lowers exercise-induced oxidative stress and homocysteine levels in overweight and obese older adults, associated with CVD. Considering the benefits of RT on body composition in obese men and women, the question is are there any studies that have investigated the effects of RT in obese adolescents? The majority of RT research with children to date has focused on preadolescents and the safety and efficacy of this type of training rather than the potential metabolic health benefits. There is only a small amount of evidence that children and adolescents may derive metabolic health-related adaptations from supervised RT. However, methodological limitations within the body of this literature make it difficult to determine the optimal RT prescription for metabolic fitness in children and adolescents, and the extent and duration of such benefits. More robustly designed single modality randomized controlled trials utilizing standardized reporting and precise outcome assessments are required to determine the extent of health outcomes attributable solely to RT and to enable the development of evidence-based obesity prevention and treatment strategies in this cohort. Furthermore, further studies with postintervention follow-ups of at least six months are required in order to assess whether RT prescriptions can be maintained as part of a regular lifestyle, and whether improved body composition can be maintained over longer periods.

**2.3. Metabolic Risk Reduction.** Epidemiologic studies show a strong association for obesity with CVD [51] and type 2 diabetes (T2D) [52]. Obesity-induced risk factors such as plasma cholesterol, elevated plasma glucose, and elevated blood pressure increase the risk for CVD and have thus been called the “metabolic complications” of obesity [53]. Published evidence indicates that the risk for CVD associated with the metabolic syndrome is greater than the sum of its individual risk factors [54]. Apparent is that improved glycemic control, decreased fat mass, improved blood lipid profiles, and decreased blood pressure are important factors in reducing coronary heart disease (CHD) in people with metabolic risk.

**2.3.1. Dyslipidaemia.** At present, a small amount of conflicting data exists on the effects of RT on blood lipid levels in healthy elderly people, and in patients with dyslipidaemia. In a recent trial, 131 subjects were randomly assigned to an RT group, an AET group, a combined RT and AET group, or a nonexercising control group [55]. Findings demonstrated that exercise mode did not impact upon blood lipids. In contrast, total cholesterol (TC), low-density lipoprotein cholesterol (LDL), and plasma triglyceride (TG) were significantly lower in all groups. These data are

comparable with another study that investigated the effects of RT and AET on metabolic parameters in 60 obese women [56]. After 20 weeks of training without diet, significant decreases in TG and TC levels were noted in each of the study groups. Fahlman et al. demonstrated that both AET and RT groups experienced increased high-density lipoprotein cholesterol (HDL-C) and decreased TG at the end of a 10-week training period in 45 healthy elderly women [57]. The RT group (at 80% of 1-RM) also had significantly lower LDL-C and TC compared with controls. These favourable changes occurred without concurrent changes in weight or diet.

None of the above studies included patients with abnormal lipid profiles. Unfortunately, no information is available on the effects of RT on subjects with dyslipidaemia. Several earlier studies examined the relationship between RT and plasma lipoprotein levels, with mixed results. In one study, premenopausal women were randomly assigned to an RT program or a control group for 5 months [58]. The RT group showed a significant decrease in TC and LDL-C, while no significant changes were noted in serum HDL-C or TG levels in either group. Changes in body composition showed no significant correlations with changes in TC or LDL-C. Another study determined the effects of 20 weeks of RT on lipid profiles in sixteen untrained males with abnormal lipoprotein-lipid levels and at least two other risk factors for CHD [59]. The training program resulted in no significant changes in plasma concentrations of TG, TC, and HDL-C. These results are in agreement with those that determined the effects of 12 weeks of RT (at 60% to 70% of 1-RM) on lipoprotein-lipid levels in sixteen sedentary obese women [60]. In contrast, another study examined the effects of 16 weeks of high-intensity RT on risk factors for CHD in eleven healthy, untrained males [13]. The RT program resulted in a 13% increase in HDL-C, a 5% reduction in LDL-C, and an 8% decrease in the TC/HDL-C ratio, despite not showing changes in body weight or percent body fat.

These findings indicate that RT has the potential to lower risk factors for CHD, independent of changes in body weight or body composition. The results of a prospective study that focused on lipid and lipoprotein levels in previously sedentary men and women undergoing 16 weeks of RT were similar [61]. Women participants demonstrated a 9.5% reduction of TC, a 17.9% decrease in LDL-C, and a 28.3% lowering of TG. Among the men, LDL-C was reduced by 16.2%, while the ratios of TC and LDL-C versus HDL-C were lowered by 21.6% and 28.9%, respectively. Thus, RT may result in favourable changes in lipid and lipoprotein levels in previously sedentary men and women. However, limitations exist; only one of the above-mentioned studies was conducted with subjects with dyslipidaemia, and no information is available about the effect of RT on patients with dyslipidaemia alone.

**2.3.2. Type 2 Diabetes.** Most available studies relate to AET in the treatment of insulin resistance (IR) and type 2 diabetes (T2D). Several systematic reviews focused on the relationship between exercise and/or physical activity and glycemic control in patients with T2D [62–64]. Results indicated that

physical training significantly improves glycemic control and reduces visceral adipose tissue and plasma TG in people with T2D, even without weight loss.

RT has been shown to improve insulin-stimulated glucose uptake in patients with impaired glucose tolerance or manifest T2D [48]. RT, and subsequent increases in muscle mass, may improve glucose and insulin responses to a glucose load in healthy individuals [65, 66] and in diabetic men and women [67, 68] and improves insulin sensitivity in diabetic or insulin-resistant middle-aged and older men and women [68–71]. In addition, high-intensity RT has been found to decrease glycosylated haemoglobin (HbA1c) levels in diabetic men and women, regardless of age [21, 22, 72–76].

A recent meta-analysis of 27 randomized controlled trials examined the effects of different modes of exercise on glucose control, and risk factors for complications in patients with T2D [77]. Results demonstrated that differences among the effects of AET, RT, and combined training on HbA1c were minor. For training lasting  $\geq 12$  weeks, the overall effect was a small beneficial reduction (HbA1c  $0.8\% \pm 0.3\%$ ). Aerobic and combined exercise had small or moderate effects on blood pressure (BP). All three modes of exercise produced trivial or unclear effects on blood lipids. The effects of RT on glycemic control and risk factors associated with CVD in T2D were small (HbA1c), unclear (BP), or trivial (blood lipids). Findings supported the notion that combined training was generally superior to RT alone.

The clinical significance of a 0.5% decrease in HbA1c can be gauged by examining large prospective intervention studies investigating morbidity and mortality outcomes in people with T2D [78]. Data suggests that a 1% rise in HbA1c represents a 21% increase in risk for any diabetes-related death, a 14% increased risk for myocardial infarction, and a 37% increased risk for microvascular complications. The impact of a decrease of 0.5% HbA1c equates to a 50% improvement towards a target value of 7% HbA1c, and a 25% improvement towards a normal value of 6% HbA1c, for a person diagnosed with 8% HbA1c.

It is unclear whether an improvement in glycemic control can be maintained in the longer term. For example, in the 6-month postintervention follow-up period reported by one author [79], participants continuing with supervised RT (at 70% to 80% of 1-RM) maintained the improvement in glycemic control, whilst in a 6-month home-based follow-up group, the improvements were lost [80]. The hypothesized reason for this difference is the difficulty of motivating people with T2D to maintain RT prescriptions as part of a regular lifestyle.

In another study [22], the combination of RT (at 70% to 80% of 1-RM) and moderate dietary restriction was associated with a threefold greater decrease in HbA1c levels after 6 months compared with moderate weight loss without RT. This result was not mediated by concomitant reductions in body weight, waist circumference, and FM. It is apparent that an increase in LBM after RT may be an important mediator in improved glycemic control. One study specifically discussed the effects of an increase in the number of GLUT4 transporters [48], because the transporter

protein GLUT4 expression at the plasma membrane is related to fibre volume in human skeletal muscle fibres [81]. A further study found that the improvement in LBM after a 10-week moderate RT-program had a greater impact on HbA1c levels than the reduction in FM, suggesting that increases in muscle mass improved glycemic control [72]. Furthermore, RT-induced changes in HbA1c have been inversely correlated with changes in the quadriceps cross-sectional area [71]. It has been proposed that hyperglycemia has a direct adverse effect on muscle contractile function and force generation [82].

A recent meta-analysis sought to investigate the existence of a dose-response relationship between intensity, duration, and frequency of RT and the metabolic clustering in patients with T2D [83]. Findings demonstrated that RT significantly reduced glycated hemoglobin by 0.48% HbA1c (95% CI: 0.76 to  $-0.21$ ,  $P = .0005$ ), fat mass by 2.33 kg (95% CI:  $-4.71$  to 0.04,  $P = .05$ ), and systolic BP by 6.19 mmHg (95% CI: 1.00 to 11.38,  $P = .02$ ). There was no statistically significant effect of RT on TC, HDL-C, LDL-C, TG, and diastolic BP. It appears that RT regimes of longer duration are most beneficial, whilst higher intensity more likely has a harmful effect on glycemic control. The meta-analysis confirmed the notion that RT does not increase BP (as was once thought), and that RT may even benefit resting BP. The BP-lowering effect of RT seems to be independent of weight loss and is believed to be mediated via reduced sympathetically induced vasoconstriction in the trained state [84, 85]. It should be noted that a decrease of approximately 6.2 mmHg for resting systolic BP is significant, since a reduction of as little as 3 mmHg in systolic BP has been estimated to reduce CHD by 5–9%, stroke by 8–14%, and all-cause mortality by 4% [86]. Progressively higher volumes of RT may reduce resting systolic BP, and more significantly, diastolic BP. Interpretive caution is warranted, due to the fact that the above analyses were based on a limited number of study groups.

### 3. Prescription of Resistance Training

It is well understood that when performed regularly and with sufficient intensity, RT stimulates skeletal muscle to synthesize new muscle proteins (hypertrophy). However, the effective amount of RT to promote muscle growth in relatively sedentary diseased or aged individuals is an area in need of further investigation. It is believed that 1 to 2 sets of 8 to 12 repetitions per set with an intensity greater than 60% of 1-repetition maximum (1RM—the maximum load that can be lifted once only throughout a complete range of motion), with 8 to 10 exercises per session and 2 to 3 sessions per week, are likely to be beneficial for maximising the health effects of increased skeletal muscle mass [87]. A recent study examining the effects of systematic RT in the elderly ( $76.2 \pm 3.2$  years) demonstrated that RT consisting of two training sessions per week was at least as efficient as RT involving three training sessions per week, provided that the number of sets performed was equal [88]. These findings contradict results of a previous study reporting that RT three days per week elicits superior strength gains when compared with RT

two days per week [89]. However, the latter study was low volume: higher frequency produced better results. A more recent review demonstrated that there was no difference in mean rates of increase in the whole muscle cross-sectional area between two and three RT sessions per week for longer periods of training [90]. But, caution is urged on the fact that the methods (machines, dynamometer) of measuring muscle strength and expressing it (absolute, relative to body weight or muscle mass) are not standardized. Thus, the true increases in muscle strength are difficult to determine in research protocols. Therefore, to compare results of different studies, muscle strength should be determined in kilo pound (kp) or Newton (N; SI unit).

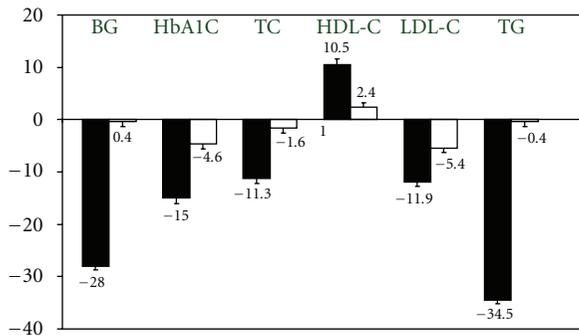
Systematic reviews comparing RT frequencies in patients with metabolic or cardiovascular risk revealed no apparent association between RT frequencies and changes in risk factors for CVD [91, 92]. However, it should be noted that only a few studies were conducted with subjects with metabolic risk, and most of the included RT studies had a training frequency of three days per week. Regression-based analyses from recently performed meta-analysis by Strasser et al. suggest there is no apparent association between RT frequency and glycemic control, but indicate a trend to a negative correlation for some outcomes of lipid profile in patients with abnormal glucose regulation [83]. The effect of RT on resting systolic BP and diastolic BP seems to be dose-dependent, since decreases in resting BP were more pronounced when the RT program was of high volume. Apparent was that relatively modest increases in RT frequency had hypotensive effects, since resting BP was reduced to a greater extent when exercising three times per week compared to twice a week [83].

On the basis of a combination of literature findings and in-house laboratory results [21, 79, 88, 93–95], some basic recommendations for the design of programmes for elderly adults with metabolic risk based are provided.

- (i) During the first two weeks of exercise, the weights should be kept to a minimal level so that patients learn the exercise techniques. A minimal weight allows muscles to adapt to the training and prevents muscle soreness.
- (ii) From the third week, the objective of the training is hypertrophy. Participants should start with three sets per muscle group per week, on 3 nonconsecutive days of the week. One set should consist of 10–15 repetitions, without interruption, until severe fatigue occurs and completion of further repetitions is impossible.
- (iii) The training load should be systematically increased to keep the maximum possible repetitions between 10 to 15 per set. A repetition maximum of 10 to 15 repetitions corresponds with 60–70% 1-RM [15].
- (iv) The number of sets for each muscle per week should be increased progressively every four weeks by one set to a maximum of 10 sets per week on (Table 1).

TABLE 1: Systematic adjustment of the weekly RT volume in sets per muscle group per week (S/MG/W) for improvement in maximum strength in rehabilitation, health, and leisure sports.

Stage	S/MG/W	Frequency
1	1	1-2
2	2	2
3	3	2
4	4	2
5	6	2-3
6	8	2-3
7	10	2-3



BG: Blood glucose  
 TC: Total cholesterol  
 TG: Plasma triglyceride  
 HDL-C: High-density lipoprotein cholesterol  
 LDL-C: Low-density lipoprotein cholesterol  
 HbA1C: Glycated hemoglobin

FIGURE 1: Percent change in metabolic parameters after 4 months RT (black) or AET (white) in patients with T2D. Whiskers represent standard deviation [18].

- (v) The RT program should consist of exercises for all major muscle groups. Exercises to strengthen the upper body could include bench press (pectoralis), chest cross (horizontal flexion of the shoulder joint), shoulder press (trapezius), pull downs (latissimus dorsi), bicep curls, tricep extensions, and exercises for abdominal muscles (sit-ups). Lower body exercises could include leg press (quadriceps femoris).

#### 4. Conclusions

Based on this review of the literature, there is a strong support for the notion that RT is at least as effective as AET in reducing some major cardiovascular disease risk factors (Figure 1). Findings demonstrate that RT may be an effective alternative to improve body composition and maintain reduced FM in obese patients after exercise training or energy intake restriction. Furthermore, it has been shown that RT preferentially mobilizes the visceral and subcutaneous adipose tissue in the abdominal region. There is now substantial support for RT decreasing glycosylated hemoglobin levels in people with an abnormal glucose metabolism and improves tendency lipoprotein-lipid profiles. Decreased fat

mass, improved glycemic control and blood lipid profiles are important for reducing microvascular and macrovascular complications in people with metabolic risk. On this basis, RT is considered a potential adjunct in the treatment of metabolic disorders by decreasing known major risk factors for metabolic syndromes. As such, RT is recommended in the management of obesity and metabolic disorders.

#### Conflict of Interests

The authors have no conflict of interests that are directly relevant to the content of this original research paper.

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## Review Article

# Physical Activity and Obesity: Biomechanical and Physiological Key Concepts

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Overweight (OW) and obesity (OB) are often associated with low levels of physical activity. Physical activity is recommended to reduce excess body weight, prevent body weight regain, and decrease the subsequent risks of developing metabolic and orthopedic conditions. However, the impact of OW and OB on motor function and daily living activities must be taken into account. OW and OB are associated with musculoskeletal structure changes, decreased mobility, modification of the gait pattern, and changes in the absolute and relative energy expenditures for a given activity. While changes in the gait pattern have been reported at the ankle, knee, and hip, modifications at the knee level might be the most challenging for articular integrity. This review of the literature combines concepts and aims to provide insights into the prescription of physical activity for this population. Topics covered include the repercussions of OW and OB on biomechanical and physiological responses associated with the musculoskeletal system and daily physical activity. Special attention is given to the effect of OW and OB in youth during postural (standing) and various locomotor (walking, running, and cycling) activities.

## 1. Introduction

Excess body weight and a low level of physical activity are closely linked. The 2004 Canadian Community Health Survey showed that obesity rates in adults were significantly higher in sedentary men (27%) compared to both moderately active (17%) and active individuals (20%) [1]. The rates of obesity were also higher in sedentary (27%) and moderately active women (21%) than in active women (14%) [1]. The Copenhagen City Heart Study also showed cross-sectionally that individuals with a high body mass index [(BMI, in kg of body mass  $\times$  (height in m)<sup>-2</sup>] are more sedentary than those with a lower BMI [2]. However, the longitudinal portion of the study, where 5142 individuals were evaluated every 5 years over a 15-year period, revealed novel findings: (1) physical inactivity at one point in time was not associated with the subsequent development of obesity (OB) while (2) the development of OB was associated to the subsequent reduction in physical activity levels [2].

These findings apply to adults, and Shields [3] proposed, based on this cross-sectional study, that physical activity levels of children do not differ according to body weight status when the overall activity level is considered. Fulton et al. (2009) reported that physical activity of moderate to vigorous intensity correlates negatively with two adiposity indexes: BMI and fat mass index, representing BMI  $\times$  percent body fat  $\times 100^{-1}$  [4]. Altogether, these findings indicate that age and physical activity type specificities are present in the relationship between physical activity and body weight status.

Inactivity as a potential cause and/or result of OB is of great interest considering the growing obesity rates. Worldwide, over 400 million adults were reported to be OB in 2005, and by 2015, more than 700 million individuals are expected to have this condition [5]. In Canada, OB has increased from 14 to 23% of adults in the last 25 years [1] and from 3 to 8% in children [3]. With such high numbers of OB individuals, it is crucial to understand

these individuals' specific activity levels in order to plan and offer adapted interventions to counteract their expected reduction in physical activity. The beneficial effects would be to slow down, and even stop, the progression of weight gain in individuals with more severe classes of OB or to bring an OB individual into the overweight (OW) or normal weight (NW) range. Likewise, OB individuals could benefit from the cardiometabolic benefits of an active lifestyle to reduce their higher risks of diabetes, hypertension, and other cardiovascular diseases [1] as well as to reduce the risk of musculoskeletal conditions such as knee and hip osteoarthritis (OA) [6, 7].

The general purpose of this paper is to better understand the impact of OW and OB on motor activities, with a special focus on children. More specifically, Section 2 aims to present general information on structural and muscular particularities that need to be taken into account for OW and OB individuals. The effect of excess body weight on three major daily living activities is then presented in Sections 3, 4, and 5, respectively, on standing, walking, and cycling. Biomechanical and physiological concepts will be presented for each activity. This structure will ease a more extensive understanding of the situation of OW and OB individuals performing these activities and could support the development of adapted interventions. The last section highlights concepts that deserve attention for program development and research areas that warrant consideration in a near future.

## 2. Obesity and Musculoskeletal Disorders

**2.1. Structural Specificities.** Overweight and obesity in adults lead to alterations of the musculoskeletal system that could put OB individual at higher risk of musculoskeletal pain [6–9]. Comparing OB (BMI  $38.8 \pm 6.0 \text{ kg} \times \text{m}^{-2}$ ) and NW adults (BMI  $24.3 \pm 3.0 \text{ kg} \times \text{m}^{-2}$ ) Hills et al. [8] reported that OB individuals had higher plantar pressure, especially under the longitudinal arch and on the metatarsal heads both when standing and walking. Other studies found a strong link between the BMI and knee OA [10–13]. In a large single-blinded, randomized control clinical trial, Messier et al. [6] showed that weight loss of about 5% resulting from a combination of diet and physical exercise improved function and mobility and reduced pain in OW and OB adults with OA. However, both musculoskeletal pain and OA are mid- to long-term consequences of obesity and affect almost exclusively adults.

Studies in children and adolescents also showed an effect of OW on both foot structure [14, 15] and the plantar pressure distribution [16] that could lead OW and OB children to be more likely to experience foot discomfort during weight-bearing activities [16]. In a study, Mickle et al. [14] compared the foot characteristics derived from footprints and reported lower plantar arch height in OB children (age  $4.3 \pm 0.9$  years; BMI,  $18.6 \pm 1.2 \text{ kg} \times \text{m}^{-2}$ ) compared to NW children (age  $4.3 \pm 0.7$  years; BMI,  $15.7 \pm 0.7 \text{ kg} \times \text{m}^{-2}$ ). The authors proposed that this difference could be due to structural modifications of the foot due to the excess of bodyweight and that is more likely to

cause functional complications in the adulthood. However, a correlation with a more direct measurement of the foot structure such as a radiographic could have strengthened the results of this study.

OB individuals have also been shown to modify the force alignment and consequently the distribution of forces at the knee during weight bearing. This has led several researchers to link alterations in force distribution, particularly those associated with varus malalignment (the load-bearing axis is shifted inward, causing more stress and force on the medial compartment of the knee), to the development of OA in obese adults [17–23]. In a review, Wearing et al. [24] highlighted that it was still unclear whether varus malalignment was the consequence or the cause of knee OA. In the pediatric OB population, the knee has been reported to be a common site of pain [25], while Gushue et al. [26] reported that OB children have an abnormal knee load during walking and concluded that, in the long term, this modification in the gait pattern could increase the risk of developing knee OA. There is a lack of a longitudinal study to determine the exact role of OB during childhood and in the development of OA. However, malalignment of the lower limbs has been linked to an increase in musculoskeletal discomfort during walking in OW children [24, 25].

**2.2. Muscles, Physical Function, and Energy Expenditure.** The muscular system is a complementary component to consider. Zoico et al. [27] investigated the importance of muscle mass in 167 elderly women and found that functional limitations, assessed by questionnaires and strength measurements, are a key parameter linked to activity energy expenditure. This group was the first to show that a BMI greater than or equal to  $30 \text{ kg} \times \text{m}^{-2}$  is significantly associated with a higher level of functional limitation; 65% of OB women reported at least one limitation as opposed to 38% of NW and 41% of OW women. Unfortunately, the dichotomization of the limitation status (at least one versus none) impedes the assessment of the magnitude of the limitation profile of individuals with at least one limitation in the OB, OW, and NW groups. A second finding of this study is that a low relative fat free mass (FFM), expressed as  $\text{kg of FFM} \times \text{body height (m)}^{-2}$ , is not associated with more physical limitations per se, but rather that a low percentage of FFM significantly increases the odds of functional limitations [27]. Thus, the ratio of the FFM to the total body mass appears to be important in identifying individuals at higher risk of functional limitations, and to a greater extent than the amount of FFM relative to their height. In other words, individuals require sufficient FFM to perform activities with an enlarged body mass. In this study, no significant differences were noted in the functional limitations of sarcopenic individuals, who have by definition an extremely low lean body mass. This is further reinforced by the fact that the absolute amount of lean body mass, expressed by height, in  $\text{m}^{-2}$ , is not a key factor of physical mobility in this study. However, Stenholm et al. [28] showed that in adults aged 65 and over, low muscle strength combined with OB is associated with a slower walking speed, a higher sedentary level, a more rapid decline in strength, and a higher rate of new disabilities inhibiting mobility.

In fact, the combined effects of adiposity and strength are present in regard to physical abilities. Therefore, muscle qualities such as strength, endurance, and FFM should be considered, along with adiposity itself, in physical activity practice and the energy equilibrium of OB adults. While these studies were conducted in older adults, the association between BMI, FFM, muscle qualities, and physical function in children remains unknown. Currently, energy expenditure and body composition is the only acquired knowledge for that population. A unique study conducted in 836 youths confined to a metabolic chamber for 24 hours, the reference method, revealed that FFM is the single largest contributor not only to the total energy expenditure, but also to the sleeping and activity energy expenditure [29]. Interestingly, Aucouturier et al. [30] showed that the FFM is higher in OB children in comparison to NW children and that the power generated per unit of FFM is the same in both groups. Consequently, the FFM in OB individuals is present in greater amounts and in a similar quality, which can at least partially compensate for an increased body weight. Currently, it remains unknown whether FFM also contributes to the musculoskeletal integrity and physical function of youths, although its importance in increasing the resting and activity energy expenditure is known.

### **3. The Impact of Excess Body Weight on Standing**

*3.1. Biomechanical Profile.* During childhood, postural stability is considered to be a major component of the child's development. Morphological changes due to growth interfere with postural stability and lead to high variability in balancing strategies in children less than 6 years old [31]. In light of the latter, could the morphological changes due to obesity modify postural balance in children? Goulding et al. [32] used the Equitest Sensory Organization Test (SOT) to compare 25 OW and 47 NW boys aged between 10 and 21 years. The SOT test assesses the contributions of vestibular, visual, and somatosensory system contribution to balance and consists of three conditions where the force plates are stationary (eyes open, eyes closed, sway referenced visual surround) and three conditions where the force plates move (sway referenced conditions: eyes open and eyes closed, and one condition with sway-referenced visual surround) [33]. Despite the fair to good reliability of the SOT in children [34], it failed to discriminate postural balance between the NW and the OB groups. This led the authors to conclude that postural imbalance in OB was rather due to an insufficient musculature for their weight, than to proprioception or sensory function disturbances. However, a difference in bipodal balance between these groups is most likely to be infraclinical and would consequently be better served by a more sensitive assessment such as that of posturography.

The authors also used the Bruininks-Oseretsky balance test scores. The Bruininks-Oseretsky subtest of balance consists of three tasks of static unipodal stance (on the floor and on a balance beam) with eyes open and eyes closed, as well as five tasks assessing dynamic balance using different

walking conditions (walking on a line, walking forward on a balance beam, walking forward heel-to-toe on a line, walking forward heel-to-toe on a balance beam, and stepping over a stick on the balance beam) [32]. Their results showed that the OW subjects had lower balance scores than the NW subjects. Furthermore, the Bruininks-Oseretsky score was moderately correlated (negative correlation) with the BMI, body weight, percentage of fat mass, and total fat mass assessed by a dual energy X-ray absorptiometry (DEXA) scan. The postural balance difference between groups was more apparent during a challenging one-leg stance on a balance beam, with both eyes open and closed. Similar results have been reported by Deforche et al. [35] comparing 25 OW to 32 NW children aged from 8–10 years. The OW group could not hold a unilateral standing position on a balance beam for as long as the NW. The study also assessed dynamic postural task such as heel-to-toe walking and tandem walking. Despite the wider base of support used by the OW children during normal walking they were able to complete both narrow walking tasks. However, they performed the tandem walking at a slower walking speed than did the NW and completed fewer steps in the heel-to-toe walking than the NW group, possibly to increase postural stability [35]. Taken together, these results highlighted that OW children might be at greater risk of postural instability than NW in activities in which a narrow base of support is required. However, postural instability might not be exclusively related to activities involving a narrow base of support and has also been reported during a sit-to-stand task with self-determined foot placement. The sit-to-stand task has previously been used to assess functional lower limb strength between 13 OB children and 13 NW children [36]. The OB children took more time to complete the weight transfer from the seated to the standing position compared to NW children. Similar results were reported by Deforche et al. [35], with OW children being slower than NW children when asked to achieve 5 consecutive sit-to-stand repetitions. In a second sit-to-stand task in which the children had to rise from a seated position 30 cm above from the floor, OW children took twice the time to do the weight transfer compared to the NW group. Moreover, the trunk kinematics was different from that of the NW group which involved a backward motion to initiate the weight transfer and a greater sway velocity while standing. In addition to the possible difficulty in OW to control the large inertia of the trunk, the difference between groups could also be attributed to insufficient lower limb strength relative to their weight [35, 36].

However, differences between OB and NW children have been reported even in tasks that required minimal muscular strength such as quiet standing. Using force platforms, static posturography showed that OW and OB during growth could interfere with postural stability [32, 37]. McGraw et al. [37] have compared postural control in 10 OB and 10 non-OB children aged between 8 and 10 years old during quiet standing. The study was designed to assess postural stability in normal and challenging foot and visual conditions. A normal side-by-side position and a tandem foot position were used, along with normal, conflicted vision and dark

environments. In both NW and OB children, postural stability performance was decreased in conditions where vision and the base of support were challenged concurrently. However, in OB children, the tandem position and the visually challenged conditions decreased their postural stability, as determined by their larger center of pressure (CoP) displacement in both the anterior-posterior and the medial-lateral directions. While McGraw et al. [37] found no difference between the groups in the quiet standing with eyes open conditions, Nantel et al. [38] reported on subjects of similar age, significantly larger CoP amplitudes, as well as higher CoP velocities in the medial-lateral direction in the OB group when compared to the NW group. This difference between results in these studies could be due to methodology used to assess quiet standing. Indeed, Nantel et al. [38] used trials of 120 seconds while McGraw et al. [37] recorded the signal for 26.5 seconds. However, this latter difference was not discussed by the authors.

Taken together these studies suggest that OB children may be disadvantaged when asked to stand still for a mid to long period of time and that they are more affected by visual conflict and foot placement than NW children. Nantel et al. [38] proposed that this instability in quiet standing could be exacerbated in dynamic conditions and may increase the risk of falling in OB children. To another extend, McGraw et al. [37] concluded that these differences could have an impact on OB children's confidence in participating in physical activities. However, the small sample size used in these studies make the conclusion difficult to extend to the children OW and OB population in general.

**3.2. Physiological Characteristics.** Energy expenditure is another parameter that differs in the standing position according to body weight status. Lafortuna et al. [39] reported that upright standing in sedentary OB women ( $n = 15$ ) requires significantly more energy than in sedentary NW women ( $n = 6$ ). Based on their results, OB women consumed an additional  $0.1 \text{ L} \times \text{min}^{-1}$  of oxygen when standing, which corresponds to 126 kJ per hour based on the assumption that a liter of oxygen reflects an expenditure of about 21 kJ [40]. Obese individuals would then use 5040 kJ more than NW individuals if both stand for a 40-hour period. In theory, standing for a moderate to long period of time could, however, be associated with a higher fatigue level in OB individuals, especially if they are in poor physical condition. In adults (12 men and 12 women) without excess body weight, standing while performing clerical work was associated with a net increase in energy expenditure of  $17 \text{ kJ} \times \text{hour}^{-1}$  [41]. On the basis of Lafortuna et al.'s [39] study, this should be even higher in OB individuals. However, NW subjects who took part in the study mentioned that they would prefer to replace sitting on a chair with sitting on an exercise ball, a position that uses an equivalent energy expenditure of  $17 \text{ kJ} \times \text{hour}^{-1}$ , before standing. The postural and musculoskeletal impacts of this work position are, at the moment, unknown in OW and OB individuals. Further studies are warranted before recommendations for the prolonged used of an exercise ball at work are brought forward. The absence of studies conducted in children also

limit extrapolation of these findings to this population as well as to active individuals since only sedentary individuals were selected [39] or the physical activity level of participants was not specified [41]. The principal limit to consider pertains to methodological perspective. Current studies have reported an energy expenditure measured in the last five minutes of a 20-minute task conducted in laboratory settings. It remains unknown whether posture would change and individuals would lean on external support after 20 minutes, and thus, energy expenditure would be modified.

## 4. The Impact of Excess Body Weight on Walking

**4.1. Biomechanical Profile.** In adults, an increased body weight leads to major modifications in the gait pattern. OW and OB individuals have been shown to walk with a shorter step length, lower cadence and velocity, a decrease in the duration of the simple support phase and an increased double support phase [9, 42]. Kinematic adaptations, such as a reduction in the range of motion at the knee and ankle, have also been reported [9, 42, 43]. Most of these changes have been associated with an increased load at the knee and the development of OA [6, 7, 42, 44–47]. Messier et al. [7] reported a positive association between body mass and compressive forces resultant forces and the abductor moment at the knee in OB adults with OA. Furthermore, a modest weight reduction of 9.8 N (less than 1 kg) was associated with a reduction of about 40 N in both compressive and resultant forces as well as with a reduction in the knee abduction moment. Similarly, comparing 10 OB adults with NW, Browning and Kram [44] showed that OB individuals had a peak knee extensor moment about 50% higher than NW when walking at  $1.5 \text{ m} \times \text{s}^{-1}$  while a slight reduction in the walking speed to  $1.0 \text{ m} \times \text{s}^{-1}$  reduced the knee peak extensor moment by 43% in OB adults. However, OB individuals walking at  $1.1 \text{ m} \times \text{s}^{-1}$  had the same knee extensor moment as NW individuals walking at  $1.5 \text{ m} \times \text{s}^{-1}$ . In contrast, DeVita and Hortobágyi [43] reported a strong inverse relationship between the BMI and knee torque in OB individuals. Indeed, the altered kinematic gait pattern observed in the OB group was associated with a decreased torque at the knee at a self-selected pace (slower than the NW subjects). They also reported a knee torque similar to that of the NW group when walking at the same pace in spite of their higher body mass. However, these results were difficult to compare with results from other studies since the authors reported their results without normalizing for the bodyweight. At this time, there is no consensus in the literature on whether these modifications are directly related to the changes in morphology and limb alignment or if they are an adaptation to reduce pain in the presence of OA or to increase dynamic postural stability. As proposed by Messier et al. [7], longitudinal studies are needed to assess the long term effects of OW and weight loss on the gait pattern and OA progression.

The spatiotemporal differences between NW and OW children are similar to those reported in adults. OW children have a longer gait cycle and stance phase duration as well as a reduced cadence and velocity compared to NW

[37, 48]. Using kinematic and kinetic analyses, Hills et al. [48] compared 10 NW and 10 OW children. They reported less flexion at the knee and hip, as well as a flatter foot pattern during weight acceptance and an external rotation of the foot during the entire gait cycle in the OW children compared to NW children. Using a similar methodology Schultz et al. [49] compared 10 OB with 10 NW children aged between 8 to 12 years old and showed no difference in the kinematics between their groups, while Gushue et al. [26] reported a lower peak knee flexion during the stance phase in OW children, similar to the results in adults [43]. Gushue et al. [26] have suggested that the lower knee flexion could be a compensation strategy to avoid increasing the extensor load due to the large increase in body mass. However, this strategy in the sagittal direction could interfere with the ability of children to control the abductor moment at the knee. Indeed, the abduction moment at the knee has been shown to be larger in OW children [26, 49]. Both groups proposed that this alteration in the frontal plane of motion could have long-term orthopedic implications. However, this latter conclusion has not been yet verified longitudinally.

In addition to the possible long-term limitations, Hills et al. [48] concluded that the gait pattern adaptations in OB children could be used to reduce the dynamic instability caused by the large body mass. Furthermore, they have proposed that the difficulty OB children have in adapting to different walking speeds might be a disadvantage when participating in physical activities involving frequent speed changes. Looking at spatiotemporal and kinetic during a self-selected pace walking task, Nantel et al. [50] showed that OB children were mechanically less efficient than NW children. Indeed, during the stance phase, despite a large absorption of mechanical energy in the hip flexor muscles, OB children were less efficient than NW children in transferring mechanical energy within the hip flexor muscles from the stance phase to the swing phase. Their results showed that compared to NW children, OB children used more mechanical energy when walking at the same speed.

*4.2. Physiological Characteristics.* Butte et al. [29] showed with a room respiration calorimeter that the energy expenditure in 460 OW children walking at  $1.25 \text{ m} \times \text{s}^{-1}$  was significantly greater than in 376 NW children, by about  $5.25 \text{ kJ} \times \text{min}^{-1}$ . This finding supports a good agreement in bioenergetics of walking using both physiological and biomechanical analysis in NW, OW, and OB individuals. However, it has also been shown in adults that the net cost of transportation ( $\text{J} \times \text{kg}^{-1}$  for a given distance) is similar for OB and NW individuals at low speeds, such as  $1 \text{ m} \times \text{s}^{-1}$  (0% incline):  $2.7 \text{ J} \times \text{kg}^{-1} \times \text{stride}^{-1}$  in OB and  $2.6 \text{ J} \times \text{kg}^{-1} \times \text{stride}^{-1}$  in NW individuals [39]. The authors expressed values per stride because no differences were noted among the groups at a given speed and incline. This is concordant with another study that showed that the oxygen consumption per kg of FFM was similar in OB, OW and NW girls for a walk at a similar speed ( $1.1 \text{ m} \times \text{s}^{-1}$ ) [51]. However, this finding should not be extended to higher speeds, at which dissociation in the net cost of transportation is noted.

At  $1.3 \text{ m} \times \text{s}^{-1}$  (4% inclination),  $4.6 \text{ J} \times \text{kg}^{-1} \times \text{stride}^{-1}$  is expended in OB youth and  $4.1 \text{ J} \times \text{kg}^{-1} \times \text{stride}^{-1}$  in NW youth, a significant difference [51]. This is similar to other results that show a higher discrepancy in the gross oxygen consumption ( $\text{L} \times \text{min}^{-1}$ ) between OW and NW young adults as speed increases: 53% difference at  $0.5 \text{ m} \times \text{s}^{-1}$  versus 70% at  $1.75 \text{ m} \times \text{s}^{-1}$  in women and 29% and 47% in men for the same speeds [52].

With this higher energy expenditure at greater walking speeds, due in part to excess body weight and lower mechanical efficiency, it should not be a surprise that the absolute aerobic performance of OB youth is lower. Mastrangelo et al. [53] examined the running performance of OB children using a 1.6 km walk-run test and found that the running performance of OB children is lower. Significant differences were noted in terms of the body weight status when the minute oxygen consumption in ml per kg of body weight (48.3 in NW boys versus 41.6 in OB boys and 46.0 in NW girls versus 42.1 in OB girls) or the time to cover the distance (10 min, 34 sec in NW boys versus 13 min, 8 sec in OB boys and 13 min, 15 sec in NW girls versus 14 min, 44 sec in OB girls) composed the performance indicators.

Sometimes, the difference between the cardiorespiratory fitness of NW and OW children does not reach statistical significance [54]. However, the study of McGavock et al. [54] showed that a low oxygen consumption at baseline, expressed as  $\text{ml} \times \text{kg}^{-1} \times \text{min}^{-1}$ , as assessed by a field test such as the Leger 20 m shuttle run, is predictive of a greater subsequent body weight increase and waist circumference. In fact, the risk of being classified as OW 12 months after the baseline evaluation was 3.5 times higher in children with low cardiorespiratory fitness (CRF) [54]. This appears to be an interesting tool in identifying children who do not have excess body weight yet but are at higher risk and might thus benefit from a primary prevention program. It is also similar to studies in adults conducted over more than 15 years in which a high CRF at baseline was associated with lower odds of obesity at followup [54]. Interestingly, McGavock et al. [54] showed that OW children tended to have a 75% reduced odds of remaining OW if their CRF was high at baseline (i.e., about  $50 \text{ ml} \times \text{kg}^{-1} \times \text{min}^{-1}$ ). Therefore, a secondary prevention program to maintain a high CRF or increase the CRF in children with excess body weight appears justified. Studies conducted in Finland between 1976 and 2001 confirmed that the running performance of children had worsened over the years, but that the leisure time physical activity level and OB status explained a higher percentage of aerobic fitness in 2001 than in 1976 [55]. This can be encouraging because leisure time physical activity self-reporting is recently more popular among youth [56]. Despite this, it might not be sufficient to counteract the sedentary lifestyle outside organized sports. Also, the study indicates that more children are active during leisure time. However, a first limit of the study is the use of self-report assessment and a second limit is that the extent (frequency, duration, and intensity) of their physical activity in 1976 and 2001 was not monitored and could differ.

Structured physical activity programs can be beneficial to regulate body weight. The eight-month program conducted

in Germany that includes behavioral and nutritional components reduced the disparities between OB children ( $n = 49$ ; 8–12 years old) and age-matched reference values for aerobic tests and some musculoskeletal tests where body weight can limit performance (e.g., push-ups) [57]. More specific interventions that help children with excess body weight overcome barriers associated with weight-bearing physical activities appear to be needed. A study conducted with OW girls revealed that, when compared to NW girls, they perceived equally that both peers and parents encouraged the practice of weight-bearing activities, which is good for their health, for a healthy outlook and for social relationships [58]. However, OW girls report more barriers to perform such activities, they find them to be less fun, they perceived themselves as performing poorly to a larger extent, and they have a lower self-efficacy toward the practice of weight-bearing activities than NW girls. The study shows that even mothers of OW girls are aware that these activities are less fun for their daughters in a larger proportion than the mothers of NW girls. While it has been shown that barriers are higher in girls [59], it indicates that at least in girls, and potentially to a lower extent in boys, programs might address these important issues for both compliance to the intervention as well as persistence of an active lifestyle postintervention.

Several points must be taken into account regarding the CRF of OB children. First, a lower performance on a walk-run test, as characterized by a higher time to cover a given distance, a lower number of stages completed, a lower maximal speed, or a lower oxygen consumption expressed in  $\text{ml} \times \text{kg}^{-1} \times \text{min}^{-1}$  does not necessarily indicate a lower fitness profile. In fact, the absolute energy expenditure that OB individuals can generate can be higher despite a lower performance in terms of time or stages. An estimate of the energy deployed by the individuals can be estimated by multiplying the common CRF indicator ( $\text{ml}$  of oxygen consumed  $\times \text{kg}^{-1} \times \text{min}^{-1}$ ) by  $0.021 \text{ kJ} \times \text{ml}$  of oxygen consumed $^{-1}$ , the mean energetic equivalent of oxygen, and by body weight, in kg. If everything other than body weight is held equal, an individual of 40 kg who jogs at  $8 \text{ km} \times \text{h}^{-1}$ , which represent eight metabolic equivalents or  $28 \text{ ml} \times \text{kg}$  of body weight $^{-1} \times \text{min}^{-1}$ , would expend  $23.5 \text{ kJ} \times \text{min}^{-1}$ . For a child 25% lighter (i.e., 30 kg), the energy expenditure would be reduced by a quarter, leading to an energy expenditure of  $17.6 \text{ kJ}$  per minute of jogging at the same speed. Considering the lower mechanical efficiency with increased body weight, it is possible that the energy expenditure of the heavier child is even higher than what general guidelines of energy expenditure suggest. No compendium of physical activity taking body weight status into consideration is currently available and individual assessment is necessary for precise measurements. If such measures are performed, the oxidative capacity of FFM is a good indicator of muscle quality that could also be measured. In order to appreciate this parameter, oxygen consumption can be reported per kg of FFM, assessed by bioimpedance scales or a DXA scan, for example. Then, more information on the abilities of muscles to perform cardiovascular work is available.

The measurement of ambulatory activities represents another important challenge from both the evaluation and

intervention point of view. Pedometers are affordable devices that individuals can wear to provide objective measures of physical activity levels. Tudor-Locke et al. [60] reported that 6- to 12-year-old girls and boys should take a minimum of 12,000 and 15,000 steps per day, respectively, to avoid OB. A major concern, however, is the accuracy of the step count with an increased body weight. Comparative studies clearly show that four factors reduce the step count accuracy: the type of pedometer, a low ambulatory speed, a tilted position of the pedometer, and a high body weight [61]. Piezoelectric pedometers are more suited to all individuals, but especially for OW and OB individuals, than spring-levered pedometers based on the technology in which a suspended horizontal lever arm moves in response to the hip's vertical accelerations [61]. In adults with a BMI greater than 25, spring-levered pedometers significantly underestimated actual steps at speeds of  $54\text{--}94 \text{ m} \times \text{min}^{-1}$  by about 35%, while a piezoelectric pedometer, the New Lifestyle NL-2000, underestimated actual steps by an average of only 7% at  $54 \text{ m} \times \text{min}^{-1}$  ( $P < .05$ ) and was within 3% at speeds of  $67\text{--}107 \text{ m} \times \text{min}^{-1}$  [61]. In children, the difference in the accuracy of steps recorded according to the type of pedometer was not conclusive [62]. Clearly, the accuracy is extremely low for walking speeds of children with or without excess body weight. However, overall measurements were more precise for NW than OW children, regardless of the type of pedometer used. Recently, the utility of accelerometers worn at the ankle compared to pedometers was justified for both NW and OW children because errors were considerably lower than with pedometers and no difference was noted according to the body weight statuses of the children [62]. Perhaps the difference in the ambulatory activities during normal conditions of NW and OW individuals would be less if measured with more precise devices, but that remains to be demonstrated.

## 5. The Impact of Excess Body Weight on Cycling

While walking and running are good physical activities to lose weight, they imply supporting body weight at each step. When an individual has an excess of body weight such locomotor activities are surely much difficult and may be associated with various musculoskeletal discomfort and or pain. An alternative is to look for nonweight bearing locomotor activities such as cycling. However, to our knowledge most studies looking at cycling in OB used a more physiological approach.

Obese youth expend more energy than non-OB individuals to perform activities in which the body weight is not supported. But what about energy expenditure when the body weight is supported? Studies addressing this question have been conducted with girls and women. A first study done with OB, OW, and NW girls indicates that the difference in energy expenditure during activities like cycling or riding a scooter are lower than that observed for walking [51]. Unfortunately in the latter study, the restriction to only female limits the extrapolation to all the population. Despite the small differences, studies conducted in OB women showed higher oxygen consumption

( $L \times \text{min}^{-1}$ ) for a given cycling intensity when compared to NW women, which indicates higher energy expenditure. This higher oxygen consumption and thus energetic output makes it more difficult for individuals with excess body weight to perform a given cycling activity. Aerobic capacity, reported per kg of body mass, is often used as discussed previously in this paper, and OB individuals have been shown to have a lower aerobic capacity [63]. This exacerbates the difficulty in performing cycling activities; the action of cycling at a given output represents a higher percentage of their maximal capacity. An important fact is that the sole action of cycling without resistance requires more energy in OB individuals, especially for high revolutions per minute. At 0 Watt of external resistance, the slope of the regression line between revolutions per minute and energy expenditure is greater for OB than NW individuals [64]. At 0 Watt and 60 revolutions per minute, a common cycling speed used in clinical settings for physical tests, OB individuals spend about 33% more energy, or an extra  $50 \text{ J} \times \text{s}^{-1}$ , than NW individuals. This clearly shows that the body weight support conferred by the bike does not cancel all the difficulty associated to excess body weight.

Experimentally induced weight gain or weight loss is very informative to better understand the bioenergetics of weight changes. Goldsmith et al. [65] induced in a controlled clinical environment either a 10% weight gain or a 10% weight loss in NW and OB individuals ( $n = 30$ ; 53% men) while maintaining a training regimen during the experiment. Mechanical efficiency and energy expenditure were measured on an ergometer bicycle both before and after weight changes. On one hand, they showed that muscle work efficiency increased by 15% at low intensity exercise (<25 Watts) after body weight loss, whereas muscle work efficiency was reduced by 25% at low intensity (10 Watts) after weight gain. On the other hand, no change in skeletal work efficiency was measured when cycling at 50 Watts and after weight loss or at 25 Watts and after weight gain. The impact of weight thus appears to be more important at low absolute intensities. In youth, Butte et al. [29] reported that cycling at 20 Watts (light intensity) and at various speeds with a mean of 57 Watts (moderate intensity) was more demanding in terms of energy needed for OW than NW individuals. In OW boys, light and moderate intensities required  $3.8$  and  $2.9 \text{ kJ} \times \text{m}^{-1}$  more than in NW boys, while in OW girls, an additional  $2.1$  and  $3.8 \text{ kJ} \times \text{m}^{-1}$  were required, respectively [29]. Based on the study by Goldsmith et al. [65], cycling for 60 minutes at 10 watts was associated with an energy expenditure of 613 kJ at baseline versus 798 kJ after a 10% body weight gain. Therefore, cycling without external resistance, an activity potentially overlooked due to its low intensity, appears to be of greater interest from the perspective of exercise prescription. Another consideration for exercise planning is that individuals who lose weight with effective interventions should either extend the duration or increase the intensity to maintain energy expenditure and avoid weight regain; the same 60 minutes of cycling at 10 watts will reduce energy expenditure from 714 to 596 kJ after a 10% weight loss [65].

At maximal exertion, similar [63] or higher [39] maximal oxygen consumption ( $L \times \text{min}^{-1}$ ) is obtained in OB individuals. Despite this, OB women generate less power, by 18 Watts on average than NW women due in part to lower mechanical efficiency [66]. Maximal oxygen consumption is however lower in OB individuals when expressed per kg of body mass, as found with submaximal intensities, while no difference is noted per kg of FFM [39]. Therefore, similar oxygen consumption per unit of FFM suggests that on an ergocycle, maximal muscle capacities are the same regardless of body weight status. Interestingly, reasons to terminate a maximal test differ according to body weight status. Musculoskeletal pain was far more commonly reported in OB than in NW women (19 versus 4%, resp.) as a reason to terminate a maximal test performed on an ergocycle [66]. OB women also report that they end the test less frequently because of leg fatigue (16 versus 38%). Together, these findings indicate that musculoskeletal pain is an important factor that limits the execution of a maximal effort.

## 6. Considerations for Physical Activity Program Development and Research Perspectives

Both OW and OB have been associated with changes in musculoskeletal structure and mobility. While changes in the gait pattern have been reported at the ankle, knee, and hip, modifications at the knee level might be the most challenging for articular integrity. Several studies have reported a knee overload in OB individuals when walking at a normal or fast speed and have highlighted a possible role in the development of OA. Consequently, a reduction in walking speed has been recommended to avoid musculoskeletal degeneration in OB adults. However, weight reduction was shown to reduce pain, improve mobility, and reduce the load at the knee in OB adults. A higher speed is one key parameter in weight reduction because of the associated higher energy expenditure, especially for individuals with a higher body weight status. Moreover, diet combined with a one-hour training program three times a week, including weight training and walking, was reported to maximize weight loss when compared to diet or exercise alone. In children, the higher mechanical energy expenditure while walking makes it a good exercise to lose weight. Higher intensity activities such as fast walking or activities with frequent speed changes should be proposed depending on the presence of pain or dynamic postural instability. These studies highlighted the complexity of physical activity prescription in OB populations, especially in the presence of postural instability, pain, or OA.

Activities in which the body weight is supported appear to be an alternative to high intensity activities with potentially fewer musculoskeletal constraints. To the best of our knowledge, no studies have documented the biomechanical parameters linked to OA and other disorders in OB individuals during cycling. Based on studies of individuals who were standing, walking or cycling, training on an elliptical trainer, in which the body weight is not necessarily supported by a device but where the individual stands and trains without the impact associated with walking or running, could be

an interesting compromise. Again, this would need to be confirmed in further studies.

What emerges from current studies is that simple movements such as standing, walking at low speed and cycling without resistance or with very low resistance should not be neglected. They increase energy expenditure and could be part of a healthy lifestyle when included in training programs as active recovery. Building the confidence of OB individuals practicing physical activities, even if the intensity appears low, is important because some of them, potentially more girls, report low confidence in physical activity. Including how physical activity and the fitness profile are reported and interpreted could improve the compliance of an OB individual in physical activity. Addressing only the time to cover a distance or the frequency and intensity of activities performed without taking into account body weight and, thus, energy expenditure results in an underestimation of the actual work performed. For example, the ratio of total energy expenditure to basal energy expenditure in OW and NW children was reported to be similar for various activities including walking and cycling [29]. Of course, most OB individuals would benefit from an increase in their energy expenditure; a good integration of biomechanical and physiological specificities might help optimize energy expenditure and musculoskeletal integrity.

## 7. Conclusion

Obesity and OW are two conditions for which the impact on physical activities goes far beyond the important body fat accumulation. Major changes were noted for foot, knee, and hip structures and are associated with discomfort, pain, and illness. This can seriously impede daily physical activity level and limit the performance of OB and OW persons during fitness tests.

For exercise prescription, we have shown that not all activities present the same difficulties at different intensities. Cycling is more demanding at low intensity for OW and OB individuals while ambulatory activities are more difficult at high intensities. Strategies like slowing the self-selected walking pace, shortening step length, or reducing resistance should be considered in exercise prescription for individuals with excess body weight, and this includes children. A good understanding of biomechanical and physiological profile is mandatory for safe testing and effective prescription of physical activity in OW and OB individuals. Future researches should look at the effect of varying biomechanical constraints (cadence, step length, inclination) and physiological demands (various intensities) on energetic expenditure to optimize training effect.

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## Review Article

# High-Intensity Intermittent Exercise and Fat Loss

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The effect of regular aerobic exercise on body fat is negligible; however, other forms of exercise may have a greater impact on body composition. For example, emerging research examining high-intensity intermittent exercise (HIIE) indicates that it may be more effective at reducing subcutaneous and abdominal body fat than other types of exercise. The mechanisms underlying the fat reduction induced by HIIE, however, are undetermined. Regular HIIE has been shown to significantly increase both aerobic and anaerobic fitness. HIIE also significantly lowers insulin resistance and results in a number of skeletal muscle adaptations that result in enhanced skeletal muscle fat oxidation and improved glucose tolerance. This review summarizes the results of HIIE studies on fat loss, fitness, insulin resistance, and skeletal muscle. Possible mechanisms underlying HIIE-induced fat loss and implications for the use of HIIE in the treatment and prevention of obesity are also discussed.

## 1. Introduction

Most exercise protocols designed to induce fat loss have focused on regular steady state exercise such as walking and jogging at a moderate intensity. Disappointingly, these kinds of protocols have led to negligible weight loss [1, 2]. Thus, exercise protocols that can be carried out by overweight, inactive individuals that more effectively reduce body fat are required. Accumulating evidence suggests that high-intensity intermittent exercise (HIIE) has the potential to be an economical and effective exercise protocol for reducing fat of overweight individuals.

HIIE protocols have varied considerably but typically involve repeated brief sprinting at an all-out intensity immediately followed by low intensity exercise or rest. The length of both the sprint and recovery periods has varied from 6 s to 4 min. Most commonly the sprints are performed on a stationary cycle ergometer at an intensity in excess of 90% of maximal oxygen uptake ( $\dot{V}O_{2\max}$ ). Subjects studied have included adolescents, young men and women, older individuals, and a number of patient groups [3–12]. The most utilized protocol in past research has been the Wingate test which consists of 30 s of all-out sprint with a hard resistance [13]. Subjects typically perform the Wingate test 4 to 6 times separated by 4 min

of recovery. This protocol amounts to 3 to 4 min of exercise per session with each session being typically performed 3 times a week for 2 to 6 weeks. Insight into the skeletal muscle adaptation to HIIE has mainly been achieved using this type of exercise [13]; however, as this protocol is extremely hard, subjects have to be highly motivated to tolerate the accompanying discomfort. Thus, the Wingate protocol is likely to be unsuitable for most overweight, sedentary individuals interested in losing fat. Other less demanding HIIE protocols have also been utilised. For example, we have used an 8-second cycle sprint followed by 12 s of low intensity cycling for a period of 20 min [5]. Thus, instead of 4 to 6 sprints per session, as used in Wingate protocol studies, subjects using the 8 s/12 s protocol sprint 60 times at a lower exercise intensity. Total sprint time is 8 min with 12 min of low intensity cycling. For the HIIE Wingate protocols, total exercise time is typically between 3 to 4 min of total exercise per session. Thus, one of the characteristics of HIIE is that it involves markedly lower training volume making it a time-efficient strategy to accrue adaptations and possible health benefits compared to traditional aerobic exercise programs. This review summarises results of research examining the effect of different forms of HIIE on fitness, insulin resistance, skeletal muscle, subcutaneous, and abdominal fat loss.

## 2. Acute Response and Chronic Adaptations to High-Intensity Intermittent Exercise

Acute responses to HIIE that have been identified include heart rate, hormones, venous blood glucose, and lactate levels, autonomic, and metabolic reactivity. Heart rate response is dependent on the nature of the HIIE protocol but typically is significantly elevated during exercise and declines during the period between sprint and recovery. For example, Weinstein et al. [14], using the Wingate protocol, recorded peak heart rates of 170 bpm immediately after a 30-second maximal all-out cycle sprint. Heart rate response to the 8 s/12 s protocol typically averages around 150 bpm after 5 min of HIIE which increases to 170 bpm after 15 min of HIIE [15]. In this protocol, there is typically a small heart rate decrease of between 5–8 bpm during each 12-second recovery period. A similar pattern of heart rate response was found for an HIIE protocol consisting of ten 6-second sprints interspersed with 30 s recovery. Heart rate increased to 142 bpm after the first sprint and then increased to 173 bpm following sprint ten [16].

Hormones that have been shown to increase during HIIE include catecholamines, cortisol, and growth hormones. Catecholamine response has been shown to be significantly elevated after Wingate sprints for both men and women [17, 18]. Catecholamine response to HIIE protocols that are less intensive than the Wingate protocol have also been shown to be elevated. For example, Christmass et al. [19] measured catecholamine response to long (24 s/36 s recovery) and short (6 s/9 s recovery) bout intermittent treadmill exercise and found that norepinephrine was significantly elevated postexercise. Also Trapp et al. [15] found significantly elevated epinephrine and norepinephrine levels after 20 min of HIIE cycle exercise (8 s/12 s and 12 s/24 s protocols) in trained and untrained young women. Bracken et al. [16] examined the catecholamine response of 12 males who completed ten 6-second cycle ergometer sprints with a 30-second recovery between each sprint. From baseline, plasma epinephrine increased 6.3-fold, whereas norepinephrine increased 14.5-fold at the end of sprinting (Figure 1). The significant catecholamine response to HIIE is in contrast to moderate, steady state aerobic exercise that results in small increases in epinephrine and norepinephrine [20]. The HIIE catecholamine response is an important feature of this type of exercise as catecholamines, especially epinephrine, have been shown to drive lipolysis and are largely responsible for fat release from both subcutaneous and intramuscular fat stores [21]. Significantly, more  $\beta$ -adrenergic receptors have been found in abdominal compared to subcutaneous fat [22] suggesting that HIIE may have the potential to lower abdominal fat stores. Aerobic endurance training increases  $\beta$ -adrenergic receptor sensitivity in adipose tissue [23]. Interestingly, in endurance trained women,  $\beta$ -adrenergic sensitivity was enhanced, whereas the sensitivity of the anti-lipolytic  $\alpha_2$  receptors was diminished [24]. However, no data are available concerning HIIE training effects on  $\beta$  or  $\alpha_2$  adrenergic receptor sensitivity of human adipocytes.

Nevill et al. [25] examined the growth hormone (GH) response to treadmill sprinting in female and male athletes

and showed that there was a marked GH response to only 30 s of maximal exercise and the response was similar for men and women but greater for sprint compared to endurance trained athletes. GH concentration was still ten times higher than baseline levels after 1 hour of recovery. Venous blood cortisol levels have also been shown to significantly increase after repeated 100 m run sprints in trained males [26], after five 15-second Wingate tests [27], and during and after brief, all-out sprint exercise in type 1 diabetic individuals [28].

Venous blood lactate response to the Wingate test protocols has typically ranged from 6 to 13 mmol·L<sup>-1</sup>. Lactate levels after the Wingate test are typically higher in trained anaerobic athletes and have been shown to be similar [18] and lower for trained women compared to trained men [17]. Lactate levels gradually increase during longer, lower intensity HIIE protocols. Trapp et al. [15] showed that 8 s/12 s HIIE for 20 min increased plasma lactate levels between 2 and 4 mmol·L<sup>-1</sup> after 5 min of HIIE for both trained cyclists and untrained females. Lactate rose to between 4 and 5 mmol·L<sup>-1</sup> after 15 min of HIIE. During a 12 s/24 s HIIE condition lactate levels of the untrained were similar but were significantly higher for the trained female cyclists (between 7 and 8 mmol·L<sup>-1</sup> after 15 min). Despite increasing lactate levels during HIIE exercise, it appears that free fatty acid transport is also increased. For example, a 20-minute bout of 8 s/12 s HIIE produced increased levels of glycerol indicating increased release of fatty acids [15] which peaked for untrained women after 20 min and after 10 min of HIIE for trained women.

HIIE appears to result in significant increases in blood glucose that are still elevated 5 min [29] and 30 min postexercise [18]. HIIE appears to have a more dramatic effect on blood glucose levels of exercising type 1 diabetic individuals. Bussau et al. [28] examined the ability of one 10-second maximal sprint to prevent the risk of hypoglycemia typically experienced after moderate aerobic exercise in type I diabetics. Twenty minutes of moderate-intensity aerobic exercise resulted in a significant fall in glycemia. However, one 10-second sprint at the end of the 20-minute aerobic exercise bout opposed a further fall in glycemia for 120 minutes, whereas in the absence of a sprint, glycemia decreased further after exercise. The stabilization of glycemia in the sprint trials was associated with elevated levels of catecholamines, growth hormone, and cortisol. In contrast, these hormones remained at near baseline levels after the 20 min of aerobic exercise. Thus, one 10-second all out sprint significantly increased glucose, catecholamines, growth hormone, and cortisol of type 1 diabetic individuals for 5 min after HIIE. Authors suggest that the addition of one 10-second sprint after moderate intensity aerobic exercise can reduce hypoglycemia risk in physically active individuals who possess type 1 diabetes.

Autonomic function has been analyzed after HIIE by assessing heart rate variability. Parasympathetic activation was found to be significantly impaired in a 10-minute recovery period after repeated sprint exercise [30] and a 1-hour recovery period [31] in trained subjects. Buchhiet et al. [30] have suggested that parasympathetic or vagal impairment is caused by the heightened sympathetic activity

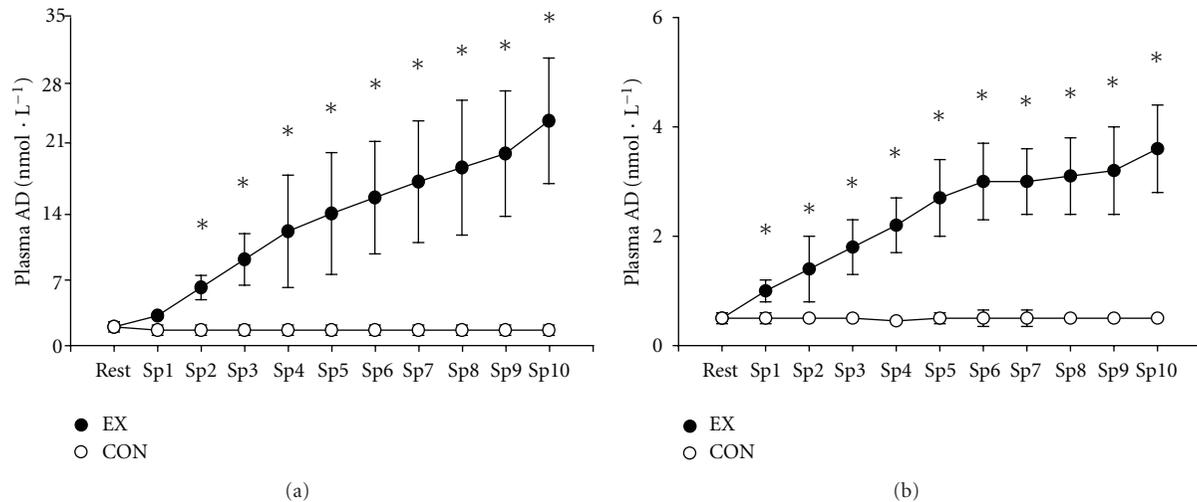


FIGURE 1: Plasma noradrenaline (NA) and adrenaline (AD) concentration of subjects at rest (CON) and following each 6-second sprint (EX) (mean  $\pm$  SD,  $n = 12$ ). \*Indicates a significant difference from equivalent CON value ( $P < .05$ ). (Adapted from Bracken et al. [16]).

that occurs during HIIE exercise and the persistent elevation of adrenergic factors and local metabolites during recovery (e.g., epinephrine, norepinephrine, and venous blood lactate).

With regard to metabolic response, HIIE initially results in decreased adenosine triphosphate (ATP) and phosphocreatine (PCr) stores followed by decreased glycogen stores [32] through anaerobic glycolysis [33]. Gaitanos et al. [29] have suggested that towards the end of an HIIE session, which consists of numerous repeat sprints (e.g., ten 6-second bouts of maximal sprinting), an inhibition of anaerobic glycogenolysis may occur. These authors have further suggested that at the end of the HIIE bout, ATP resynthesis may be mainly derived from PCr degradation and intramuscular triacylglycerol stores. However, this pattern of fuel utilization during HIIE has not been demonstrated in humans. After hard, all-out HIIE exercise, complete phosphagen recovery may take 3–4 min but complete restoration of pH and lactate to pre-exercise levels may take hours [33]. The recovery of the exercising muscle after HIIE to its pre-exercise state is undetermined. After a hard bout of aerobic exercise, recovery has typically been found to be biphasic with an initial rapid phase of recovery lasting 10 s to a few minutes followed by a slower recovery phase lasting from a few minutes to hours [33]. During recovery, oxygen consumption is elevated to help restore metabolic processes to baseline conditions. The postexercise oxygen uptake in excess of that required at rest has been termed excess postexercise oxygen consumption (EPOC). EPOC during the slow recovery period has been associated with the removal of lactate and H<sup>+</sup>, increased pulmonary and cardiac function, elevated body temperature, catecholamine effects, and glycogen resynthesis [33]. Although EPOC does not appear to have been assessed after HIIE, it is enhanced after split aerobic exercise sessions. For example, magnitude of EPOC was significantly greater when 30-minute [34] and 50-minute [35] aerobic exercise sessions were divided into two parts. Also an exponential relationship

between aerobic exercise intensity and EPOC magnitude has been demonstrated [36]. With regard to HIIE, it is feasible that the significant increase in catecholamines (Figure 1) and the accompanying glycogen depletion described earlier could induce significant EPOC. However, aerobic exercise protocols resulting in prolonged EPOC have shown that the EPOC comprises only 6–15% of the net total exercise oxygen cost [36]. Laforgia et al. [36] have concluded that the major impact of exercise on body mass occurs via the energy expenditure accrued during actual exercise. Whether HIIE-induced EPOC is one of the mechanisms whereby this unique form of exercise results in fat loss needs to be determined by future research. In summary, acute responses to a bout of HIIE include significant increases in heart rate, catecholamines, cortisol, growth hormone, plasma lactate and glucose levels, glycerol, and a significant decrease in parasympathetic reactivation after HIIE, and depletion of ATP, PCr, and glycogen stores.

Chronic responses to HIIE training include increased aerobic and anaerobic fitness, skeletal muscle adaptations, and decreased fasting insulin and insulin resistance (Table 1). Surprisingly, aerobic fitness has been shown to significantly increase following minimal bouts of HIIE training. For example, Whyte et al. [45] carried out a 2-week HIIE intervention with three HIIE sessions per week consisting of 4 to 6 Wingate tests with 4 min of recovery. Previously, untrained males increased their  $\dot{V}O_{2\max}$  by 7%. Increases in  $\dot{V}O_{2\max}$  of 13% for an HIIE program also lasting 2 weeks have been documented [42]. HIIE protocols lasting 6 to 8 weeks have produced increases in  $\dot{V}O_{2\max}$  of 4% [37] and 6–8% [39]. Longer Wingate-type HIIE programs lasting 12 to 24 weeks have recorded large increases in  $\dot{V}O_{2\max}$  of 41% [40] and 46% [6] in type 2 diabetic and older cardiac rehabilitation patients. The less intense protocols (8 s/12 s) coupled with longer duration conducted over 15 and 12 weeks resulted in a 24% [5] and 18% increase [46] in  $\dot{V}O_{2\max}$ . Collectively, these results indicate that participation

TABLE 1: Effect of high-intensity intermittent exercise on subcutaneous and abdominal fat, body mass, waist circumference,  $\dot{V}O_{2\max}$ , and insulin sensitivity.

Study	Subcutaneous fat (kg)	Abdominal/trunk fat (kg)	Body mass (kg)	Waist circumference (cm)	Type of HIIE	Length of intervention	$\dot{V}O_{2\max}$ ml·kg·min <sup>-1</sup>	Insulin sensitivity
Boudou et al. [8]	↓ 18%	↓ 44%	↓ 1.9 kg (2%)	—	SSE + 5 × 2/3 min R	8 weeks	—	↑ 58%
Burgomaster et al. [37]	—	—	↔	—	4–6 Wingate/4.5 min R	6 weeks	↑ 7%	—
Dunn [46]	↓ 2.6 kg (8%)	↓ .12 kg (6%)	↓ 1.9 kg (3%)	↓ 3.5 cm (4%)	60 × 8 s/12 s R	12 weeks	↑ 18%	↑ 36%
Helgerud et al. [39]	—	—	↓ .8 kg (1%)	—	15 s/15 s R	8 weeks	↑ 6%	—
Helgerud et al. [39]	—	—	↓ 1.5 kg (2%)	—	4 × 4 min/4 min R	8 weeks	↑ 7%	—
Mourier et al. [40]	↓ 18%	↓ 48%	↓ 1.5 kg (2%)	↓ 1.00 cm (1%)	SSE + 5 × 2/3 min R	8 weeks	↑ 41%	↑ 46%
Perry et al. [41]	—	—	↓ .2 kg (.03%)	—	10 × 4 min/2 min R	2 weeks	↑ 9%	—
Talanian et al. [42]	—	—	—	—	10 × 4 min/2 min R	2 weeks	↑ 13%	—
Tjønnå et al. [43]	—	—	↓ 2.3 kg (2.5%)	↓ 5.0 cm (5%)	4 × 4 min/3 min R	16 weeks	↑ 26%	↑ 19%
Tjønnå et al. [3]	↓ 2.4 kg (7%)	↓ 1.5 kg (8%)#	↑ .1 kg (.3%)	↓ 7.2 cm (7%)	4 × 4 min/3 min R	12 weeks	↑ 10%	↑ 29%
Trapp et al. [5]	↓ 2.5 kg (10%)	↓ .15 kg (10%)#	↓ 1.51 kg (2%)	—	60 × 8 s/12 s R	15 weeks	↑ 24%	↑ 33%
Tremblay et al. [38]	↓ 15%*	↓ 12%*	↓ .1 kg (.1%)	—	15 × 30 s	24 weeks	↑ 20%	—
Warburton et al. [44]	—	—	↓ 3.0 kg (4%)	—	7 × 2 min/2 min R	16 weeks	↑ 10%	—
Whyte et al. [45]	—	—	↓ 1.0 kg (1%)	↓ 2.4 cm (2%)	4–6 Wingate/4.5 min R	2 weeks	↑ 9%	↑ 25%

Note: ↑ indicates increased; ↓ decreased; ↔ no change; —not recorded; \*body fat was assessed by skin folds; # trunk fat; SSE = steady state exercise; Wingate = 30 s flat out sprint; R = recovery.

in differing forms of HIIE by healthy young adults and older patients, lasting from 2 to 15 weeks, results in significant increases in  $\dot{V}O_{2\max}$  from between 4% to 46% (Table 1). Mechanisms underlying the aerobic fitness response to HIIE are unclear although a major contributor is phosphocreatine

degradation during repeated HIIE. Using thigh cuff occlusion to prevent PCr resynthesis during recovery, Trump et al. [47] showed that PCr contributed approximately 15% of the total ATP provision during a third 30-second bout of maximal isokinetic cycling. Muscle glycogenolysis made

a minor contribution to ATP provision during the third 30-second bout indicating that aerobic metabolism was the major source of ATP during repeated sprinting. Similarly, Putman et al. [48] showed that repeated bouts of HIIE resulted in a progressive increase in ATP generation so that by the third out of five 30-second Wingate bouts, the majority of ATP was generated oxidatively.

Other mechanisms underlying the HIIE increase in aerobic power are undetermined but may involve increased stroke volume induced by enhanced cardiac contractility [39], enhanced mitochondrial oxidative capacity, and increased skeletal muscle diffusive capacity [10]. There is also evidence indicating that muscle aerobic capacity is increased following HIIE due to increases in PGC-1 $\alpha$  mediated transcription [49] occurring via AMPK activation [50]. Harmer et al. [7] have suggested that these marked oxidative adaptations in the exercising muscle are likely to underlie the significant increases in peak and maximal oxygen uptake documented after regular HIIE.

Anaerobic capacity response to HIIE has typically been assessed by measuring blood lactate levels to a standardized exercise load or anaerobic performance on a Wingate test. A number of studies have demonstrated that HIIE lasting from 2 to 15 weeks results in significant increases in anaerobic capacity from between 5% to 28%. For example, Tabata et al. [51] used a 20 s/10 s protocol and found that in previously untrained males, anaerobic capacity, measured by maximal accumulated O<sub>2</sub> deficit, was increased by 28%. Whyte et al. [45] carried out a 2-week HIIE intervention and found that previously untrained males increased their anaerobic capacity by 8%, whereas Burgomaster et al. [32] found that Wingate test performance was increased by 5.4% after two weeks of HIIE.

A number of studies have taken muscle biopsies after Wingate test performance in order to examine skeletal muscle adaptations. In a series of studies, Gibala et al. [13, 52] have consistently found increased maximal activity and protein content of mitochondrial enzymes such as citrate synthase and cytochrome oxidase after HIIE training. For example, Talanian et al. [42] carried out an HIIE intervention that consisted of 2 weeks of HIIE exercise performed seven times with each session consisting of ten 4-minute bouts at 90%  $\dot{V}O_{2\max}$  separated by 2-minute resting intervals.  $\dot{V}O_{2\max}$  was increased by 13% and plasma epinephrine and heart rate were lower during the final 30 min of a 60-minute cycling steady state exercise trial at 60% of pretraining  $\dot{V}O_{2\max}$ . Exercise whole body fat oxidation also increased by 36%, and net glycogen use was reduced during the steady state cycling trial. HIIE significantly increased muscle  $\beta$  hydroxyacyl coenzyme A dehydrogenase and citrate synthase. Total muscle plasma membrane fatty acid binding protein content also increased significantly after HIIE. Thus, seven sessions of HIIE, over two weeks, induced marked increases in whole body and skeletal muscle capacity for fatty acid oxidation during exercise in moderately active women. Other studies have found similar results with studies reporting large increases in citrate synthase maximal activity after 2 weeks [32] and 6 weeks of HIIE [37]. Similarly,  $\beta$  hydroxyacyl coenzyme A dehydrogenase activity, which catalyzes a key

rate-limiting enzyme step in fat oxidation, also significantly increased after HIIE training [38]. Increases in oxidative muscle metabolism (e.g., hexokinase and citrate synthase activity) after 7 weeks of HIIE training with type 1 diabetic individuals have also been documented [7]. Collectively, markers of muscle oxidative capacity have been shown to significantly increase after six sessions of HIIE lasting as little as 2 weeks. Glycolytic enzyme content and activity has also been shown to increase after exposure to HIIE. Tremblay et al. [38] have shown that 16 weeks of HIIE significantly increased phosphofructokinase levels which is a key rate limiting enzyme in glycolysis, whereas Macdougall et al. [53] also showed increases in phosphofructokinase with a Wingate-type protocol carried out for 7 weeks. In summary, Wingate test HIIE protocols of between one and seven weeks have demonstrated marked increases in skeletal muscle capacity for fatty acid oxidation and glycolytic enzyme content and activity.

The effect of HIIE training on fasting insulin and insulin resistance is shown in Table 1. As can be seen all studies that have assessed insulin response to HIIE have recorded significant improvements of between 23% and 58% increase in insulin sensitivity. Insulin sensitivity has typically been assessed by measuring fasting insulin, HOMA-IR, and by glucose tolerance tests. In healthy, nondiabetic individuals, the improvement in fasting insulin and insulin resistance has ranged from 23% to 33% [37, 39, 42, 45], whereas in individuals possessing type 2 diabetes, two studies have reported greater insulin sensitivity improvements of 46% [40] and 58% [8]. Babraj et al. [4] used a glucose tolerance test to assess insulin sensitivity after an intervention that consisted of 2 weeks of HIIE performed three times per week with each session consisting of four to six 30-second all out sprints separated by resting interval of between 2 to 4 min. Glucose (12%) and insulin areas under the curve (37%) were significantly attenuated with a sustained improved insulin action until at least three days after the last exercise session. This was achieved without a change in body weight and with a total exercise energy increase of only 500 kcal for the two weeks. Authors suggest that the small increase in energy expenditure contrasts to the 2000–3000 kcal per week experienced during a typical aerobic training program. The mechanism(s) underlying these large increases in insulin sensitivity reported in these studies is likely due to the skeletal muscle adaptations previously discussed involving marked increases in skeletal muscle capacity for fatty acid oxidation and glycolytic enzyme content [25]. In summary, chronic exposure to HIIE results in significant increases in aerobic and anaerobic fitness, increased skeletal muscle capacity for fatty acid oxidation and glycolytic enzyme content, and increased insulin sensitivity.

### 3. High-Intensity Intermittent Exercise and Fat Loss

The majority of research examining HIIE has focused on short-term (2 to 6 weeks) programs on skeletal muscle adaptation [13]. However, some studies have utilized longer

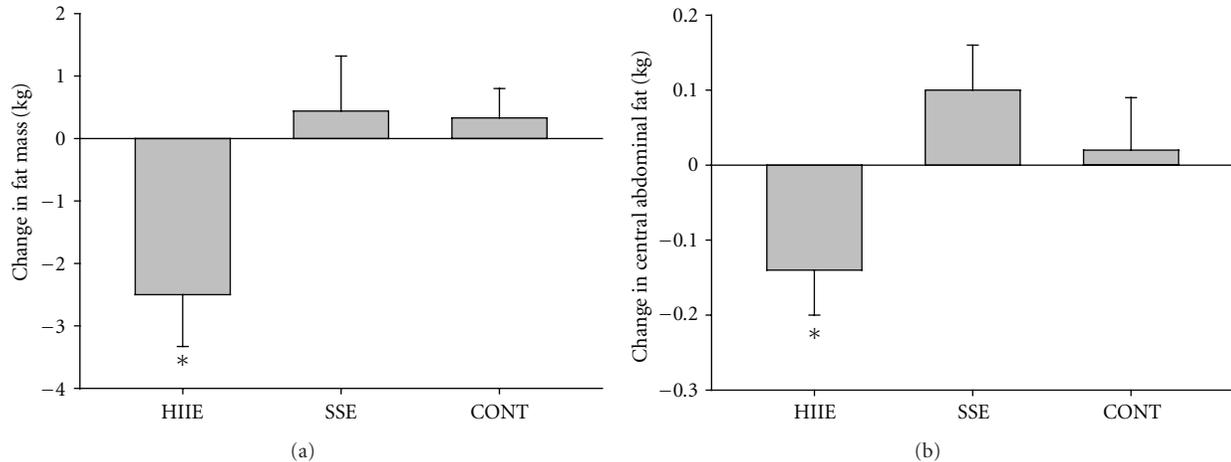


FIGURE 2: Subcutaneous (a) and abdominal fat loss (b) after 15 weeks of high-intensity intermittent exercise. HIIE: high-intensity intermittent exercise, SSE: steady state exercise, Cont: control. \*Significantly different from control and SSE groups ( $P < .05$ ). (Adapted from Trapp et al. [5]).

programs to determine the effect of HIIE on subcutaneous and abdominal fat loss. For example, Tremblay et al. [38] compared HIIE and steady state aerobic exercise and found that after 24 weeks subjects in the HIIE group lost more subcutaneous fat, as measured by skin folds, compared to a steady state exercise group when exercise volume was taken into account (Table 1). More recently, Trapp et al. [5] conducted an HIIE program for 15 weeks with three weekly 20-minute HIIE sessions in young women. HIIE consisted of an 8-second sprint followed by 12 s of low intensity cycling. Another group of women carried out an aerobic cycling protocol that consisted of steady state cycling at 60%  $\dot{V}O_{2\max}$  for 40 min. Results showed that women in the HIIE group lost significantly more subcutaneous fat (2.5 kg) than those in the steady state aerobic exercise program (Figure 2(a)). Dunn [46] used a similar HIIE protocol together with a fish oil supplementation and a Mediterranean diet for 12 weeks. In 15 overweight young women, the combination of HIIE, diet, and fish oil resulted in a 2.6 kg reduction in subcutaneous fat (8%) and a 36% increase in insulin sensitivity (Table 1). The amount of subcutaneous fat lost was similar to that observed in the Trapp et al. [5] study suggesting that shorter HIIE interventions (12 versus 15 weeks) are also effective for reducing subcutaneous fat.

With regard to abdominal fat, Trapp et al. [5] found that 15 weeks of HIIE led to significantly reduced abdominal fat (.15 kg) in untrained young women (Figure 2(b)), whereas Dunn [46] found that 12 weeks of HIIE led to a 12 kg decrease in abdominal fat. As women in these studies possessed relatively low abdominal fat levels, it is possible that the greater abdominal fat of men may demonstrate greater reductions after HIIE. For example, Boudou et al. [8], in a study involving older type 2 diabetic males, found that after 8 weeks of HIIE no change in body mass occurred; however, abdominal adiposity was decreased by 44% (Table 1). Mourier et al. [40] found a 48% reduction in visceral fat, measured by MRI, compared to an 18% decrease in subcutaneous fat following an exercise regimen consisting

of steady state exercise two days per week and HIIE one day a week for 8 weeks in type 2 diabetic men and women. Tjønnå et al. [3] examined 32 middle-aged metabolic syndrome men and women who performed 16 weeks of HIIE three times per week.  $\dot{V}O_{2\max}$  increased by 26% and body weight was reduced by 2.3 kg. Whyte et al. [45] examined ten overweight males aged 32 years after two weeks of HIIE consisting of 6 sessions of a 4–6 repeats of a Wingate test.  $\dot{V}O_{2\max}$  increased (8%) and significant change in waist circumference was also found (Table 1). Although the effects of HIIE on fat free mass has not been extensively examined, one study using DEXA found that trunk muscle mass was significantly increased after 15 weeks [5], whereas another study using MRI showed a significant 24% increase in thigh muscle cross sectional area after HIIE [8].

A summary of the results of studies examining the effects of HIIE on subcutaneous and abdominal fat, body mass, and waist circumference is illustrated in Table 1. As can be seen studies that carried out relatively brief HIIE interventions (2 to 6 weeks) only resulted in negligible weight loss. However, the majority of subjects in these short-term Wingate test studies have been young adults with normal BMI and body mass. Studies that used longer duration HIIE protocols with individuals possessing moderate elevations in fat mass [5] have resulted in greater weight/fat reduction. Interestingly, the greatest HIIE-induced fat loss was found in two studies that used overweight type 2 diabetic adults (BMI > 29 kg/m<sup>2</sup>) as subjects [8, 40]. Given that greater fat loss to exercise interventions has been found for those individuals possessing larger initial fat mass [54], it is feasible that HIIE will have a greater fat reduction effect on the overweight or obese. Thus, more studies examining the effects of HIIE on obese or overweight individuals are needed.

Possible mechanisms underlying the HIIE-induced fat loss effect include increased exercise and postexercise fat oxidation and decreased postexercise appetite. As mentioned, Gaitanos et al. [29] have suggested that towards the end of an HIIE session that consists of numerous repeat

sprints (e.g., ten 6-second bouts of maximal sprinting) an inhibition of anaerobic glycogenolysis occurs and ATP resynthesis is mainly derived from PCr degradation and intramuscular triacylglycerol stores. That increased venous glycerol accompanied HIIE in both trained female cyclists and untrained women [15] supports the notion that acute HIIE progressively results in greater fatty acid transport. Also Burgomaster et al. [55] and Talanian et al. [42] have shown that 6 to 7 sessions of HIIE had marked increases in whole body and skeletal muscle capacity for fatty acid oxidation.

As mentioned previously, the EPOC or postexercise response to HIIE does not appear to have been examined. It is feasible that the catecholamines generated by HIIE (Figure 1) could influence postexercise fat metabolism. Increased fat oxidation after HIIE may also occur as a result of the need to remove lactate and  $H^+$  and to resynthesize glycogen. The elevated GH levels documented after a bout of HIIE [25] may also contribute to increased energy expenditure and fat oxidation.

It is also feasible that HIIE may result in suppressed appetite. In rats, hard exercise has been repeatedly reported to reduce food intake [56]. The mechanisms underlying the anorectic effects of exercise are not known but exercise may reduce food intake by facilitating the release of corticotropin releasing factor (CRF) a potent anorectic peptid [56]. It has been shown that hard running and swimming exercise results in elevated levels of CRF in rats [57, 58] and increases in indirect markers of CRF in humans [59]. Rivest and Richard [57] and Kawaguchi et al. [58] showed that injecting a corticotropin-releasing factor (CRF) antagonist into the hypothalamus of rats prevented the effects of exercise on food intake and body weight reduction suggesting that CRF plays a major role in the anorexia caused by exercise in rats. Bi et al. [59] also provided evidence to support the importance of CRF in mediating the long-term effects of exercise on food intake and body weight in rats. Human studies also show a considerable decrease in subjective hunger after intensive aerobic exercise [56]. However, this exercise-induced anorexia has been observed only for a short time after hard exercise ( $>60\% \dot{V}O_{2max}$ ). Mechanisms underlying this effect in humans are undetermined but could include the CRF peptide effect previously discussed and an exercise-induced redistribution of splanchnic blood flow. For example, a 60%–70% decrease in splanchnic blood flow in humans exercising at  $70\% \dot{V}O_{2max}$  has been documented [60] and at maximal exercise splanchnic blood flow is reduced by approximately 80% [61]. In summary, there is evidence to suggest that regular HIIE results in increased fat oxidation during exercise; however, the effects of HIIE on postexercise fat oxidation and appetite suppression have not been examined.

#### 4. Conclusions and Clinical Implications

Research examining the effects of HIIE has produced preliminary evidence to suggest that HIIE can result in modest reductions in subcutaneous and abdominal body fat in young normal weight and slightly overweight males and females. Studies using overweight male and female type 2

diabetic individuals have shown greater reductions in subcutaneous and abdominal fat. The mechanisms underlying the fat reduction induced by HIIE, however, are undetermined but may include HIIE-induced fat oxidation during and after exercise and suppressed appetite. Regular HIIE has been shown to significantly increase both aerobic and anaerobic fitness and HIIE also significantly lowers insulin resistance and results in increases in skeletal muscle capacity for fatty acid oxidation and glycolytic enzyme content.

Some important issues for future HIIE research include optimization of type and nature of HIIE protocols, individual fat loss response to HIIE, and suitability of HIIE for special populations. The most utilized protocol has been the Wingate test (30 s of all-out sprint). This protocol amounts to 3 to 4 min of cycle exercise per session with each session being typically performed 3 times a week. This protocol, although remarkably short in duration, is extremely hard and subjects have to tolerate significant discomfort. Thus, the Wingate protocol is likely to be unsuitable for most overweight, sedentary individuals interested in losing fat. Other less demanding HIIE protocols have included an 8-second cycle sprint followed by 12 s of low intensity cycling for a period of 20 min [5], a 15-second cycle sprint followed by 15 s of low intensity cycling for a period of 20 min [45], and a 2-minute cycle sprint followed by 3 min of low intensity cycling for a period of 20 min [8]. A challenge for future research is to identify the minimal dose of HIIE for the maximum health benefit. As discussed earlier, reducing the length of HIIE training from 15 to 12 weeks still resulted in significant subcutaneous and abdominal fat loss [46]. Thus, more research is needed to identify the optimal length and intensity of the HIIE protocol for achieving varying health outcomes.

With regard to modality, studies have primarily utilized a stationary cycle ergometer, thus, little is known about the effects of other potential HIIE modalities such as rowing, walking, running, stair climbing, and swimming. That insulin resistance has recently been shown to primarily be located in leg muscle [62] suggests that HIIE exercise that focuses on the legs is likely to show the greatest insulin sensitivity increases. How leg muscle adaptations to HIIE impact on subcutaneous and abdominal fat loss and other health markers compared to other regional adaptations is undetermined.

It is unclear if the increase in insulin sensitivity following HIIE training is simply a response to the last exercise session or a result of more permanent skeletal muscle adaptations. Whyte et al. [45] have provided evidence to suggest that for short-term HIIE training of two weeks, the increase in insulin sensitivity was largely a result of the last HIIE session. They assessed insulin resistance 24 hours and 72 hours after the sixth HIIE session in a two-week training program. Insulin sensitivity had increased by 25% at 24 hours after HIIE but had returned to preintervention levels after 72 hours. In contrast to these results, Babraj et al. [4] used a glucose tolerance test to assess insulin sensitivity after a similar intervention and found that insulin sensitivity was improved until at least three days after the last exercise session. Why these similar HIIE protocols produced differing results

differ is not clear and also whether HIIE programs lasting longer than two weeks display a similar effect has not been established.

Individual variability in fat loss to HIIE and other forms of exercise is an important issue for future research. For example, in the intervention previously described [5] there were significant individual differences in the fat loss response to HIIE. Fat response ranged from a loss of 8 kg to a gain of .10 kg. If fat loss responders alone were examined in this study (women who lost rather than gained fat), then average fat loss was 3.94 kg. As there are likely to be responders and nonresponders in every exercise, fat loss trial calculating mean fat loss alone hides the significant fat loss achieved by some individuals. Thus, it is feasible that HIIE fat loss programs are effective for producing a clinical decrease in fat (greater than 6% of fat mass) for some but not all participants. Boutcher and Dunn [63] have highlighted a range of program design factors and individual factors that are behavioral, inherited, and physiological in origin that may affect individual fat loss response to exercise. Therefore, research is needed to identify the major individual factors that both enhance and impede fat loss response to HIIE-based interventions.

A small number of studies have examined the effects of HIIE fat loss and health of special populations and patients. These have included overweight adolescents [3], older adults [6], type 1 [7] and type 2 diabetic individuals [8], paraplegics [9], intermittent claudication [10], chronic obstructive pulmonary disease [11], and cardiac rehabilitation patients [12]. Encouragingly, these studies have shown that HIIE appears to be both safe and beneficial for these patient groups. Future research needs to establish the most beneficial HIIE protocol that is both optimal and sustainable for different types of patients.

In conclusion, regular HIIE produces significant increases in aerobic and anaerobic fitness and brings about significant skeletal muscle adaptations that are oxidative and glycolytic in nature. HIIE appears to have a dramatic acute and chronic effect on insulin sensitivity. The effects of HIIE on subcutaneous and abdominal fat loss are promising but more studies using overweight individuals need to be carried out. Given that the major reason given for not exercising is time [64], it is likely that the brevity of HIIE protocols should be appealing to most individuals interested in fat reduction. The optimal intensity and length of the sprint and rest periods together with examination of the benefits of other HIIE modalities need to be established.

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## Review Article

# Physical Activity Plays an Important Role in Body Weight Regulation

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Emerging literature highlights the need to incorporate physical activity into every strategy intended to prevent weight gain as well as to maintain weight loss over time. Furthermore, physical activity should be part of any plan to lose weight. The stimulus of exercise provides valuable metabolic adaptations that improve energy and macronutrient balance regulation. A tight coupling between energy intake and energy expenditure has been documented at high levels of physical exercise, suggesting that exercise may improve appetite control. The regular practice of physical activity has also been reported to reduce the risk of stress-induced weight gain. A more personalized approach is recommended when planning exercise programs in a clinical weight loss setting in order to limit the compensatory changes associated to exercise-induced weight loss. With modern environment promoting overeating and sedentary behavior, there is an urgent need for a concerted action including legislative measures to promote healthy active living in order to curb the current epidemic of chronic diseases.

## 1. Introduction

Regular, vigorous exercise has been necessary for survival throughout evolution. It is only during the past few decades that it has become possible for people to go through life with minimal physical activity. The modern way of living promotes comfort and well-being in a less energy-demanding environment; however, we are not genetically adapted for this sedentary lifestyle. Physical inactivity has become so prevalent that it is common to refer to exercise as having “healthy benefits,” even though the exercise-trained state is the biological normal condition [1, 2]. It has long been known that regular physical activity induces multiple adaptations within skeletal muscles and the cardiorespiratory system, all of which providing positive outcomes for the

prevention and treatment of many metabolic disorders [3, 4]. Lack of exercise should rather be perceived as “abnormal” and associated with numerous health risks. The objective for us as researchers and health care practitioners is to be more innovative in finding ways to motivate people to exercise and adopt healthier lifestyle choices.

In the field of obesity research, physical exercise has been traditionally considered as a strategy to burn calories. However, physical exercise is much more than that. It is a stimulus that, when properly managed, contributes to a significant improvement in energy and macronutrient balance regulation and to global body functioning, that is, a precise regulation of body homeostasis [5]. It thus seems appropriate to propose that an active lifestyle can influence energy balance and body fat to a much greater extent than

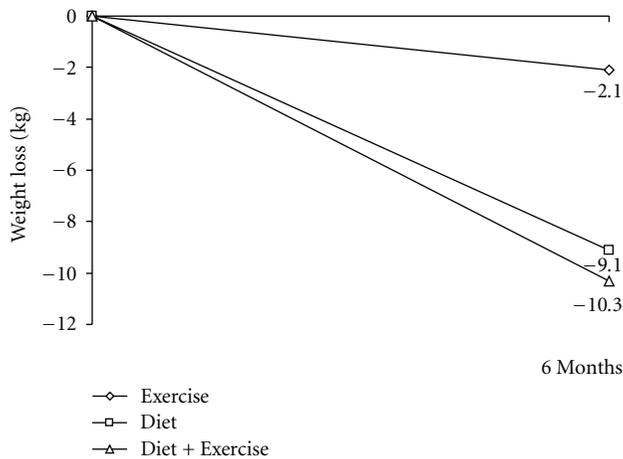


FIGURE 1: Weight loss related to an exercise intervention, a diet intervention, and a diet + exercise intervention. The magnitude of weight loss due to physical activity is additive to caloric restriction, but physical activity is generally insufficient by itself to bring about clinically significant weight loss, that is, a decrease of 5% or more in body weight. Figure adapted from Wing [6].

what is generally perceived by health professionals. To reach this outcome, exercise should ideally be performed regularly and on a permanent basis.

The main preoccupation of this conceptual paper is to discuss the critical role of physical activity in body weight regulation. The paper should not be perceived as an exhaustive literature review and critical analysis of the exercise–body weight connection, but rather an attempt to emphasize why and how physical exercise should be part of any plan to achieve body weight stability and overall health. Although the results of exercise programs designed to reduce body weight are generally considered disappointing [6] (see Figure 1), we still believe that exercise is an important player in obesity prevention and management. For the purpose of this paper, the general term “regular exercise” refers to the population-at-large consensus message that accumulation of 30 min of moderate intensity activity such as brisk walking, on at least 5 days of the week, can provide important health benefits.

## 2. Physical Exercise: More Than a Calorie-Burning Agent

There has been increasing evidence over the past decades of the importance of physical exercise in maintaining cardiovascular health and preventing diseases [7]. In recent years the list of beneficial effects has continued to grow. It has been shown that physically active individuals are less likely to develop stroke [8], some forms of cancer [9], type 2 diabetes [10], obesity [11], osteoporosis [12], sarcopenia [13], and loss of function and autonomy [14]. Evidence is also accumulating that exercise has profound benefits for brain function, including improvements in learning and memory as well as in preventing and delaying loss of cognitive function with aging or neurodegenerative disease

[15]. The knowledge gained from this large body of evidence is highlighting the crucial role of exercise to health and well-being, and it underscores the need to pay serious attention to this area of public health [7].

When sedentary individuals undertake exercise, the activity provides a massive stimulus with widespread physiological implications. The precise metabolic regulation brought about by exercise is expressed at many levels of regulatory processes, be it by stimulating the effect of key enzymes, by increasing cell sensitivity to numerous hormones, by facilitating substrate transport through membranes, by influencing cell receptors in a tissue-specific manner, and much more [5]. With the generalized sedentariness observed in modern societies, the human body needs to compensate for the lack of exercise stimulation to maintain energy and macronutrient balance. Fat gain and the metabolic syndrome are unfortunately the price to pay to maintain this balance [16].

The physiological perception of obesity considers fat gain as a biological adaptation that ultimately permits the person gaining weight to reach a new homeostatic state [17]. Some of the adaptations to this state of positive energy balance include an increase in fat oxidation [18], sympathetic nervous system activity [19], insulinemia at euglycemia [20], and leptinemia [21], all of which promoting over time the reequilibration of energy balance. However, fat gain cannot fully replace the positive impact conferred by a healthy lifestyle. The problem related to fat gain as a physiological compensation to sedentariness is that it cannot occur with the same metabolic efficiency as exercise. Specifically, fat gain relies more on increased concentration of substrates (e.g., free fatty acids) and hormones (e.g., insulin and leptin) to reequilibrate energy balance, which likely underlies the occurrence of the metabolic syndrome. These observations reinforce the relevance of adhering to healthy diet and physical activity habits in order to maintain body weight stability rather than relying on the overuse of regulatory systems soliciting the effects of hyperinsulinemia on the control of energy intake and expenditure.

In the context of weight management, it is more and more recognized that exercise should be encouraged and the emphasis on weight loss reduced [22–24]. This is concordant with the evidence that cardiorespiratory fitness is a more powerful predictor of cardiovascular and mortality risk than body weight [25, 26]. The culture of focusing on body weight as the sole indicator of success is misleading because exercise without weight loss has been reported to be associated with marked reductions in abdominal fat and increases in skeletal muscle mass [27]. Moreover, body weight *per se* does not seem to be the most important risk factor for obesity comorbidities [28–30]. It is nevertheless understandable that many people feel disappointed by the poor weight loss success of exercise.

According to King et al. [31], the general perception that exercise is futile for weight management is damaging, and a more transparent and positive attitude to the health benefits of exercise is required. Therefore, there is a need to promote physical exercise and to prevent it being undervalued by the community and by public health professionals [25, 31].

### 3. Exercise-Induced Negative Energy Balance

The ability of exercise to induce an overall body energy deficit or to prevent a positive energy balance within a given period of time depends on its energy cost, its ability to modify postexercise energy metabolism, and the postexercise compensation in energy intake [5]. Furthermore, the resulting exercise-related energy balance is influenced by exercise modalities (type, duration, frequency, and intensity) as well as the nutritional context surrounding its practice.

Beyond the energy cost of exercise, early studies have shown that an increase in energy metabolism can persist for many hours following the exposure to the exercise stimulus [32, 33]. Many years later, we confirmed this observation by demonstrating that resting metabolic rate was greater in endurance-trained individuals compared to the level predicted by their body weight [34]. Taken together, the energy cost of physical activity and its related increase in postexercise metabolic rate should normally induce a significant body weight loss if no compensation in energy intake occurs over time.

In the 1980s, Flatt [35] proposed the RQ:FQ concept according to which variations in energy balance correspond to those in macronutrient balance. In fact, since the regulation of carbohydrate and protein balance is precise, this concept ultimately implies that energy balance is equivalent to fat balance. Thus, the capacity of exercise to induce an energy deficit would depend on the ability to increase lipid oxidation above lipid intake. Importantly, this concept also emphasizes the impact of variations of body fat mass on fat oxidation. For instance, in the study of Schutz et al. [36], a change of 10 kg in fat mass was related to a change of 20 g in daily lipid oxidation in the same direction. If these results are applied to the context of a weight-reducing program, this would mean that 40 to 60 min of light to moderate exercise might be necessary to compensate for the decrease in fat oxidation resulting from a 10 kg fat mass loss. Our research experience with female elite swimmers agrees with this observation since a two-month interruption of regular intensive training resulted in a 4 kg fat gain corresponding to a positive energy balance of about 600 kcal/day [37]. Thus, one of the main clinical implications of the RQ:FQ concept is that regular physical activity seems to be necessary to compensate for the weight loss-induced decrease in fat oxidation and thus prevent weight regain in a context where fat intake would be unchanged. This is consistent with data reported by Ewbank et al. [38] who found that exobese regular exercisers regained much less body weight compared to less active subjects.

The RQ:FQ concept also helps in understanding the effects of exercise modalities on body weight. As previously reviewed in [39], increasing exercise duration is related to some accentuation of weight loss and ultimately to the occurrence of a plateau. Once again, fat loss over time has a sufficient influence on weight regulation to compensate for the stimulating effects of exercise.

Our research has also been oriented towards the evaluation of exercise intensity *per se* on energy balance and body weight. In this case, the key question is whether, “calorie

for calorie,” an increase in exercise intensity is sufficient to modify the spontaneous coupling between energy intake and expenditure. The first answer to this question was provided by the Canada Fitness Survey which showed that after statistical adjustment for the energy cost of leisure time activities, subcutaneous adiposity was lower in individuals reporting the practice of vigorous physical activities [40]. Subsequently, the comparison of two exercise training programs revealed that for a given energy expenditure of exercise, subcutaneous fat loss was greater after a high intensity intermittent exercise program compared to a more conventional endurance training program [41]. This study also showed that high intensity exercise induced a more pronounced enhancing effect on the oxidative potential of skeletal muscle. Furthermore, experiments performed under standardized laboratory conditions confirmed the effects of exercise intensity, be it on postexercise spontaneous energy intake or energy expenditure/fat oxidation. Indeed, after having performed a 500 kcal-exercise of either low or high intensity, the postexercise compensation in *ad libitum* energy intake was lower when exercise intensity was high [42]. We repeated the same experimental strategy to measure the effect of vigorous exercise on postexercise energy metabolism. Specifically, high intensity exercise accentuated postexercise resting  $\text{VO}_2$  and fat oxidation which was, however, abolished by beta blockade [43]. This finding is relevant regarding the RQ:FQ concept [35], because it demonstrates the involvement of beta adrenergic stimulation as a mechanism underlying the stimulating effect of vigorous physical activity on fat oxidation.

In summary, the experience of many decades of investigation on the impact of physical activity on body weight shows that the exercise stimulus can influence energy balance. This effect is more pronounced when prolonged vigorous exercise is performed but clinical experience indicates that some individuals may be unable to take in charge such a physical demand. According to the RQ:FQ concept, one must also keep in mind that independently of the features of the exercise regimen, metabolic adaptations occurring with fat loss will progressively attenuate the anorexigenic and thermogenic effects of prolonged vigorous activity up to complete resistance to further lose fat. The obvious corollary of this observation is that exercise will thus have to be maintained in a reduced obese state to prevent further weight regain.

### 4. Physical Exercise Improves the Accuracy by Which Energy Intake Is Matched with Energy Expenditure

Several decades ago, Mayer et al. [44] evaluated the association between caloric intake, body weight, and physical work in an industrial male population in West Bengal (India). The mill workers covered a wide range of physical exercise, from sedentary to very hard work. The authors observed that caloric intake was greater in workers exposed to a greater labor demand, but only for moderate-to-high levels of physical exercise. In contrast, energy intake and

energy expenditure were uncoupled in sedentary individuals. Indeed, energy intake was greater in sedentary workers compared to those performing light and medium work. These data are suggestive of a disruption in the accuracy by which energy intake is matched with energy expenditure at low levels of physical exercise and might explain, at least in part, why it is so difficult to prevent weight regain in sedentary individuals after a weight loss intervention. Conversely, a tight coupling between energy intake and energy expenditure has been documented at high levels of physical exercise [45, 46].

Furthermore, physical exercise has been shown to improve energy compensation in response to covert preload energy manipulation [47–49]. Indeed, active individuals seem more able to distinguish between preloads by adequately adjusting energy intake at a subsequent meal, denoting a better short-term appetite control. In contrast, sedentary individuals generally show a deficient homeostatic feedback control of hunger and satiety and are unable to distinguish between a low- and high-energy preload, and have similar energy intake at a subsequent meal [47–49]. The “long-term” effects of physical exercise on energy compensation in response to covertly manipulated preloads have also been recently investigated [50]. The authors observed an improved appetite control after a 6-week moderate intensity exercise program in normal weight sedentary individuals, with a more sensitive eating behavior in response to previous energy intake. In addition, results from a recent randomized crossover study showed that acute exercise significantly increased postprandial levels of PYY, GLP-1, and pancreatic polypeptide in normal weight adults, suggesting that exercise can trigger physiological changes in hormone secretion, which could help in appetite control [51]. The transitory increase in the plasma levels of satiety hormones reported in the latter study may help to explain the short-term suppression of hunger observed after exercise, a phenomenon that is known as “exercise-induced anorexia.” Thus, it seems appropriate to say that exercisers display a better appetite control in general than their less active counterparts. However, short-term satiety data cannot directly be extrapolated to long-term appetite control, because adaptations may occur.

## 5. Critical Role of Physical Activity in the Long-Term Weight Regulation

The role of physical activity on the long-term prevention of weight gain or maintenance of weight loss has been assessed in numerous studies in the literature. Most recently, cross-sectional data from 7 European countries in the EPIC-PANACEA survey indexed a total of 125 629 men and 280 190 women into four categories according to self-reported physical activity practice and found that physical activity was inversely associated with BMI and waist circumference [52]. Prospective cohort studies investigating the relationship between obesity and levels of physical activity over time are fairly consistent. Most studies found that people who are physical active on a regular basis are less likely to gain

weight [53–56]. Interestingly, Drøyvold et al. [56] found that subjects reporting exercise of higher intensities were less likely to gain weight than those reporting low intensity exercises, even after adjusting for baseline BMI and age. Furthermore, Kimm et al. [57] showed that a decline in physical activity in adolescence was related to increases in BMI and skin fold thickness over time. Given the risk of adolescence overweight and obesity for later development of obesity, these findings underscore the importance of physical activity in long-term weight regulation. In contrast, Petersen et al. [58] did not find a relationship between long-term physical activity participation and development of obesity. The study rather suggested that obesity may lead to physical inactivity.

The above-mentioned findings are important in establishing associations between long-term weight regulation and physical activity; however, randomized controlled trials are needed to investigate the causal relationship between these two factors. Few studies have been conducted in this area. Donnelly et al. [59] studied weight changes in response to a 16-month supervised exercise trial (45 min/day, 5 days/week) in overweight young men and women. They found that exercise produced ~5 kg weight loss in male exercisers compared to controls. Whereas in women controls the weight gain was ~3 kg, the exercisers remained weight stable. Slentz et al. [60] studied the effects of different exercise volumes and intensities over 8 months on body weight and body fat distribution in middle-aged men and women with mild-to-moderate hypertension. Without a reduction in caloric intake, loss of both body mass and fat mass occurred in a dose-dependent manner in regards to exercise volume and intensity. Furthermore, the controls gained weight throughout the study period. In the Look AHEAD trial, a total of 5145 men and women with type 2 diabetes were studied [61]. Greater self-reported physical activity was the strongest correlate of weight reduction, followed by clinically significant endpoints such as treatment attendance and meal replacements.

In general, physical activity has not been regarded as the most effective strategy for obtaining weight loss. Several systematic reviews have showed that a lower weight loss can be expected by physical activity alone compared to caloric restriction [62–64]. However, many methodological issues, such as doses of physical activity, assessment of energy balance and energy intake, and variations in baseline variables (e.g., age, weight, and percentage of body fat) have to be considered when interpreting these findings. In recent years, several well-controlled studies that carefully matched energy deficits by either caloric restriction or physical activity have shown that weight loss through exercise can be achieved [65–67]. Furthermore, weight loss induced by exercise seems to reduce total and ectopic body fatness to a greater extent than caloric restriction [65–67], which is a finding of high clinical importance.

In more aggressive weight loss strategies, physical activity also plays an important role. Evans et al. [68] studied gastric bypass surgery patients at months 3, 6, and 12 postsurgery. Patients reporting participation in at least 150 min/week of moderate-to-high intensity exercise had greater weight loss at 6 and 12 months postsurgery.

The US National Weight Control Registry, published in 2008, reports that those who are successful at maintaining weight loss (individuals maintaining a 13.6 kg weight loss for more than 1 year) are an extremely physically active group, despite a large variance in individual levels of physical activity [69]. These findings have been confirmed by Jakicic et al. [70], who studied obese women randomly assigned to 1 of 4 groups based on physical activity energy expenditure (1000 versus 2000 kcal/week) and intensity (moderate versus vigorous) with a concomitant decrease in daily dietary energy intake (−1200 to −1500 kcal/day). Despite no difference in weight loss at 6 and 24 months between the groups, post hoc analyses showed that individuals sustaining a loss of 10% or more of initial body weight at 24 months reported performing more physical activity (1835 kcal/week or 275 min/week) compared to those sustaining a weight loss of less than 10% of initial body weight.

The reasons for this association between high levels of physical activity and successful maintenance of weight loss in the long term are not fully understood; however, it is probably related to the maintenance of resting metabolic rate or total daily energy expenditure. Redman et al. [71] randomized overweight subjects to either a low calorie diet (~900 kcal/day), caloric restriction of 25% of daily energy requirements, or 12.5% caloric restriction plus 12.5% increase in energy expenditure by structured exercise. The authors observed that 6 months of caloric restriction resulted in a metabolic adaptation characterized by a reduction in free-living energy expenditure that is larger than what can be explained by changes in body weight and body composition. Furthermore, there was a reduction in free-living activity thermogenesis after caloric restriction which was prevented when caloric restriction was combined to exercise.

As mentioned previously, another explanation for the association between high levels of physical exercise and successful maintenance of weight loss in the long term pertains to the better coupling between energy intake and energy expenditure, thereby facilitating the maintenance of energy balance [46]. Finally, high levels of physical activity are associated with better adherence to energy-restricted diets [64]. All together, the emerging scientific literature highlights the need to incorporate physical activity into every strategy intended to prevent weight gain as well as to maintain weight loss over time.

## 6. Contribution of Physical Exercise to Total Energy Expenditure

Interindividual variation in total energy expenditure (TEE) is mainly a function of differences in body size and physical activity. The activity-induced energy expenditure (AIEE) as part of the TEE may contribute, under habitual conditions, to 5% in a very sedentary person [72] up to 75% in highly trained endurance athletes [73]. However, while total physical activity is positively correlated with TEE, the weight-reducing effect of intense physical activity often associated with structured exercise training/sport activities is less obvious [74]. Interventions comprising regular sessions

of physical exercise of moderate or high intensity generally produced moderate weight loss, with considerable interindividual variability, that is less than what could be expected based on theoretical calculations of the energy cost of the exercise session *per se* [75]. The obvious explanation for this is that weight loss is generally accompanied by a coinciding upregulated motivation to eat, leading to compensatory increased energy intake. Another explanation is that total 24-hour energy expenditure is not increased to the theoretically expected level in order to defend body mass. The latter explanation could be due to compensatory decreases in other daily activities, blunting the effect of exercise on TEE. A number of studies have, however, shown that the addition of moderate amounts of nonstrenuous physical activities, at least without dietary restriction, does not lead to a decrease in other activities for the remainder of the day [76–80].

The increase in TEE associated with physical exercise has actually been shown to be higher than the energy cost of the training program *per se*. Based on the results of four exercise intervention studies in nonelderly subjects [76–79], researchers found that the intervention-induced increase in TEE was in average 1.9 MJ/d, and the calculated net energy cost of the training program was of 1.0 MJ/d. These findings, combined with indications of maintained postexercise behavior, suggest that the cost of the exercise intervention was twice that could be expected from measurements or calculations of energy expenditure during the imposed exercise. Although no effects on basal metabolism were found in these studies when assessed  $\geq 36$  h after the last exercise session, it is still possible that the excess postexercise energy expenditure within this time frame partly explained these discrepancies [32, 33, 81], however, probably not to the full extent, leaving a part of this increase in TEE unexplained. Whatever the mechanisms behind these findings may be, the studies of Westerterp [82] as well as Goran and Poehlman [83] suggest that the difference between expected and measured increases in TEE is affected by the individual physical “burden” of the intervention. In the first study [82], the running distance was doubled (from 25 to 50 km/week) without any additional increase in TEE. In the second study [83], elderly subjects performed 3 intense cycling sessions weekly for 8 weeks but TEE did not increase (−0.3 MJ/d) although the energy cost of the training intervention *per se* was expected to be in average 0.6 MJ/d.

We have previously reported that extremely fit endurance athletes of both sexes, expending in average 18.3 MJ/d (women) and 30.3 MJ/d (men) during periods of intense training, have approximately 15% higher basal metabolic rates than sedentary subjects matched for age, sex, and lean body mass, even  $\geq 39$  h postexercise [73, 84]. Likewise, resistance training for 26 weeks in a previously unfit elderly population studied by Hunter et al. [85] resulted in marked increase in TEE (965 kJ/d). This was, in addition to the energy expended during the training sessions (215 kJ/d), attributed to increased resting metabolic rate (365 kJ/d) as a result of increased lean body mass as well as to additional nontraining physical activities (288 kJ/d).

A negative energy balance as a result of exercise combined with an imposed energy restriction may potentially modify

the effect of exercise on TEE. Studies looking at the influence of exercise in combination with energy restriction have found marginal further effects on body weight following the addition of exercise [86]. Body weight seems to be defended during caloric restriction, involving at least 3 mechanisms: (i) a decrease in resting metabolic rate, although partly counteracted by exercise [87]; (ii) a reduction in nonexercise physical activity [71, 88] and as recently suggested; (iii) an increase in work efficiency. For instance, Goldsmith et al. [89] showed that the work efficiency (energy output divided by energy expended above resting energy expenditure) was increased by 15% when bicycling at 50 Watts after a 10% weight reduction. This is in line with the explanation offered by Westerterp et al. [79] for the lack of further increased TEE paralleling the increased exercise volume described above.

Finally, it should be noted that dietary induced thermogenesis (DIT) increases in direct proportion to the increased TEE if energy balance is maintained. In the case of well-trained endurance athletes, this could result in DIT four times higher than an average sedentary subject. It may account for up to almost 1000 kcal/d in extreme cases and should be considered when assessing the different components of TEE.

## 7. Physical Exercise as a Buffer to the Deleterious Effects of Stress on Body Weight

The role of chronic stress in the etiology of obesity is increasingly recognized [90–96]. In turn, the stress response of obese people has been shown to be exaggerated, which may further increase the risk of weight gain. Stress management has then been suggested as a weight control strategy to stop this vicious cycle [90] and, expectedly, lifestyle interventions targeting stress reduction have shown weight-control benefits [97]. Interestingly, the state of low physical activation appears to intensify the acute response to psychological stressors [92], and consistently sedentary lifestyles potentiate the stress-related health complications such as obesity, particularly visceral obesity [91, 95]. Thus, physical activity is suggested to decrease the risk of stress-induced obesity by (i) directly reducing the stress response and (ii) indirectly buffering the harmful effect of stress, as presented in Figure 2.

In the modern environment, where energy-dense foods are highly available and food cues very powerful, people tend to eat pleasurable foods to relieve stress [93]. However, the stress-induced feeding is not only the result of the behavior-facilitating environment. When under threat, human body activates the hypothalamic-pituitary-adrenocortical (HPA) axis and the sympathetic nervous system (SNS) which leads to the release of glucocorticoids (cortisol) and catecholamines (adrenaline and noradrenaline), respectively [91, 92]. An increase in circulating cortisol is generally accompanied by hyperinsulinemia which may become chronic in the context of continuous stress [91, 92, 94]. The combined action of cortisol and insulin is known to increase the intake of pleasurable foods [94], and insulin blunts fatty acid

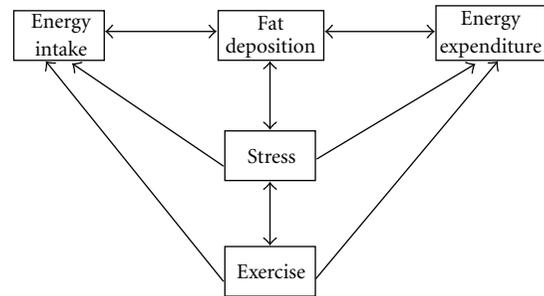


FIGURE 2: Potential influence of exercise on the interaction between stress and obesity.

oxidation which could lead to body fat gain. In addition, some evidence shows that hypercortisolemia leads to a state of leptin resistance and is also associated to an elevated neuropeptide Y release [91]. Both hormones (cortisol and neuropeptide Y) are known to stimulate appetite [98]. In turn, eating hedonic foods appears to decrease the feeling of stress [94]. It affects the corticolimbic brain areas that regulate learning, memory, reward, mood, and emotions [93]. Therefore, the stress-induced feeding habit is reinforced every time something pleasurable is eaten to relieve psychological stress [94]. This vicious cycle must then be stopped by using another stress-reduction method [96] and, for its physiological and psychological effects, exercise practice seems a good option.

The neuroendocrine response to stress also influences fat deposition. In fact, the joint action of the HPA and SNS is to mobilize energy for the “fight or flight” response that has been for long time vital for humans [91]. In today’s society, where stress is predominantly of psychosocial nature, the mobilized substrates are not used and rather stored. Since visceral adipose tissue is particularly sensitive to the combined signal of insulin and glucocorticoids, stress results in fat accumulation in the viscera [90–92, 94]. Moreover, stress-induced visceral fat deposition is further accentuated by the antithermogenic effect of cortisol [90] and the concomitant dysregulation in the thyroid axes and in the secretion of sex steroid and growth hormone [91].

In general, cross-sectional studies show a negative association between physical activity and stress levels, though such association is not significant in all of them [95]. Only few longitudinal and quasiexperimental studies have been conducted on the topic, but their results tend to support the cross-sectional evidence. For example, regular joggers showed a reduced risk of perceiving a high level of stress compared to sedentary individuals (OR = 0.33) [99]. Moreover, experimental evidence in adolescents assigned to 10 weeks of high intensity aerobic training showed beneficial effects on perceived stress level in comparison to those who engaged in moderate aerobic or flexibility training or no exercise [100].

The main rationale for using exercise as a stress reduction strategy is mostly based on the cross-stressor adaptation hypothesis [101]. This theory suggests that a bout of exercise elicits a stress response which therefore leads to beneficial

adaptations in the stress pathways that can transfer to psychosocial stressors. Although this hypothesis seemed promising in the 1990s, recent meta-analyses did not show a strong support [102–104]. Current research continues to investigate the possible mechanisms that may explain the stress-reducing effect of exercise.

The key question now is whether physical activity, which seems to modulate the level of stress, may interact in the relationship between stress and obesity. Research on such triadic relationship is at a very early stage. In fact, only one study verified specifically the three-way interaction. Yin et al. [96] showed that the interaction of stress and exercise predicted adiposity measures in adolescents. The authors of a recent review about the effect of exercise on stress and metabolic syndrome/obesity were also in favor of the beneficial effect of exercise on the relationship between stress and adiposity [92]. Different possible mechanisms suggesting that exercise training might protect against the stress-induced obesity have been proposed. Apart from its possible direct effect on the modulation of the stress response, exercise training improves insulin sensitivity, which might counteract the insulin resistance state produced by chronic hypercortisolemia [91]. The secretion of insulin could then be reduced which thereby may diminish its deleterious impact on energy intake. In addition, exercise training enhances oxidative capacity of skeletal muscle [91]. In the long run, this could prevent stress-induced fat deposition by routing the energy mobilized in response to stressor toward oxidation rather than storage. Regular exercise produces psychological improvements that may help buffering the harmful effects of stress. It has beneficial antidepressant and anxiolytic effect [91, 105] and, as shown in a recent meta-analysis, depression increases the risk to develop obesity [106]. Exercise training also improves sleep patterns [95, 105]. Considering that bad sleeping habits is itself a stressor [107] that has been associated with increased risk of obesity [108], physical activity can have a stress-buffer effect. There is also some evidence that exercise influences health-related behaviors, such as nutrition, and might help coping with life's stress, particularly among high-risk individuals [95]. Then, when practiced on a regular basis, physical activity could help breaking the stress-feeding habits.

## **8. How Can We Deal with the Interindividual Variability in Exercise-Induced Weight Loss?**

When promoting exercise training for weight loss purposes, we inevitably have to deal with the question of interindividual variability in the response to exercise training. Why some people lose weight by exercising whereas others do not? And how can we deal with these differences in a clinical setting?

Interindividual differences in the response to exercise training have been reported in the literature [75, 109, 110]. Although methodological issues can be responsible for the variability (e.g., differences in subjects' baseline characteristics) in some cases, these apparent differences can also be attributed to either compensatory behavioral

changes or physiological adaptations to training [75, 109]. The behavioral changes can be both volitional and non-volitional and include compensatory eating, reduced daily life nonexercise activities, or simply lack of compliance to the prescribed exercise program. The physiological adaptations, as mentioned earlier, may include a lower resting metabolic rate, altered substrate utilization, and improved exercise efficiency due to a better physiological functioning of both circulatory and peripheral mechanisms and structures.

It is widely accepted that, when facing energy deficit, the body reacts by upregulating energy conserving compensatory responses. Independently or in combination, these different compensatory responses (both behavioral and physiological) act as a counterbalance mechanism when exercising for the purpose of weight loss. The timing and magnitude of these mechanisms can be different. However, it is evident that the behavioral changes (volitional or non-volitional) contribute more to the compensatory component than the physiological adaptations [109, 111]. Furthermore, physiological adaptations to exercise training are not factors which can be eliminated and, thus, are not susceptible to any treatment or deliberate changes. Hence, this suggests that it is important to recognize that behavioral changes might be a strong limiting factor in terms of achieving a successful body weight regulation. It is therefore necessary to uncover the behavioral changes on an individual basis in order to address them. This not only advocates a more individual approach when planning exercise programs in a clinical weight loss setting, but more importantly the possibility to monitor the patients' eating and activity patterns and to give them support and guidance targeting behavioral aspects. This personalized approach must also include other behavioral factors that have been shown to impede the weight loss response, such as sleep deprivation, stress, depressive symptoms, and weight cycling.

As stated previously in this paper, exercise training should not be isolated as a means to maintain weight stability or lose weight but should be considered as a way to promote health, quality of life and fight off diseases. The beneficial effect of engaging in regular exercise training is independent of weight loss, and for that reason alone, exercise training should be an integrated part of any weight loss program.

## **9. Conclusion**

The vast majority of scientific evidence supports a beneficial role of exercise on achieving body weight stability and overall health. The goal is to find ways to motivate people to exercise and adopt healthy lifestyles. In order to achieve this objective, we must be innovative and creative in finding ways to fight against the modern way of living that drives excess energy intake relative to expenditure. Future research will be needed to give a better insight into the many issues impacting physical activity levels of people, including the barriers to healthy active living. Furthermore, we need to pay particular attention to the disparities in physical activity practice, because children with disabilities and those from

low socio-economic status backgrounds are at a disadvantage. With experts around the world sounding the alarm about the consequences of escalating rates of obesity, type 2 diabetes, and cardiovascular disease, a concerted action including legislative measures to promote healthy active living is more than warranted [112]. Specifically, government intervention needs to take the form of appropriate legal and fiscal measures designed to make healthy choices more affordable, accessible, and acceptable. By doing so, we expect that the population as a whole will be healthier.

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## Review Article

# Cognitive-Behavioral Strategies to Increase the Adherence to Exercise in the Management of Obesity

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Physical activity plays a major role in the development and management of obesity. High levels of physical activity provide an advantage in maintaining energy balance at a healthy weight, but the amount of exercise needed to produce weight loss and weight loss maintenance may be difficult to achieve in obese subjects. Barriers to physical activity may hardly be overcome in individual cases, and group support may make the difference. The key role of cognitive processes in the failure/success of weight management suggests that new cognitive procedures and strategies should be included in the traditional behavioral treatment of obesity, in order to help patients build a mindset of long-term weight control. We reviewed the role of physical activity in the management of obesity, and the principal cognitive-behavioral strategies to increase adherence to exercise. Also in this area, we need to move from the traditional prescriptive approach towards a multidisciplinary intervention.

## 1. Introduction

Physical activity plays a major role in human obesity. In epidemiological studies, physical activity levels were highly predictive of age-related weight gain [1, 2], and also low levels of recreational physical activity were associated with the 10-year changes in body weight gain [3]. Unfortunately, the amount of exercise needed to produce weight loss and to provide weight loss maintenance may be difficult to achieve in obese subjects, particularly in a "toxic" eating-promoting environment [4]. Mayer et al. suggested that it might become very difficult in the presence of a surfeit of food to maintain energy balance at a healthy weight in the presence of a very low level of physical activity, considering that this would imply an unsustainable calorie restriction [5]. Thus the focus for a normal weight should be more properly moved from diet and diet composition to the levels of physical activity able to match calorie intake [6].

Unfortunately, for most individuals with obesity, the adoption of exercise as a consistent lifestyle behavior is hindered by several physical, psychological, and environ-

mental obstacles [7, 8]. This underlines the importance of recognizing the psychological determinants of exercise behavior, and developing effective strategies to improve the patient's adherence to exercise.

In this paper, we address four main topics: (1) the role of exercise in weight loss programs, (2) the problem of adherence to exercise, (3) the cognitive behavioral strategies to engage patients in increasing their level of exercise, and (4) the cognitive behavior strategies to increase patients' adherence to exercise.

## 2. The Role of Exercise in Weight Loss Programs

*2.1. Exercise and Weight Loss.* The importance of physical activity in successful intervention programs for weight control has been recognized for many years. Weight-loss interventions incorporating exercise components are more effective in promoting long-term weight loss in overweight persons than are interventions that rely on dietary instruction alone [9]. Over 90% of participants in the National Weight Control Registry (NWCR), a database of successful

TABLE 1: Recommendations for physical activity in the management of obesity [13].

Evidence statements and recommendations on PA for weight loss and WL maintenance	Level of evidence	Evidence statements and recommendations on combined therapy (Diet + PA) for WL and WL maintenance	Level of evidence
(i) PA in overweight or obese adults results in modest WL independent of the effect of caloric restriction through diet	A	(i) The combination of a reduced calorie diet and increased PA produces greater WL than diet alone or PA alone	A
(ii) PA in overweight or obese adults modestly reduces abdominal fat	B	(ii) The combination of a reduced calorie diet and increased PA produces greater reductions in abdominal fat than either diet alone or PA alone, although it has not been shown to be independent of WL	B
(iii) PA in overweight or obese adults modestly increases cardio-respiratory fitness independent of WL	A	(iii) A combination of a reduced calorie diet and increased PA improves cardiorespiratory fitness as measured by $VO_{2\max}$ when compared to diet alone	A
<i>Recommendation:</i> PA is recommended as part of a comprehensive WL program because it:		<i>Recommendation:</i> The combination of a reduced calorie diet and increased PA is recommended, since it produces WL, decreases abdominal fat, and increases cardiorespiratory fitness	A
(i) modestly contributes to WL in overweight and obese adults	A		
(ii) may decrease abdominal fat	B		
(iii) increases cardiorespiratory fitness	A		
(iv) may help maintenance of WL	C		

PA, physical activity; WL, weight loss.

weight loss maintainers (over 30 lbs for at least 1 yr, on average over 60 lbs for 5.5 yr), report losing weight with food restriction and physical activity [10]. The amount of weight loss directly related to physical activity *per se* is probably low, considering the much lower degree of energy imbalance created by increased physical activity than by food restriction, but anyway it is greater than zero [11], and other advantages are expected. In subjects engaging in physical activity, a higher proportion of weight loss comes from fat [12], thus preventing the loss of lean mass which accompanies calorie deficit. Total energy expenditure would thus be higher after weight loss with physical activity versus food restriction alone, providing an advantage in weight loss maintenance.

Increased physical activity is indeed one of the best predictors of long-term success in weight reduction. In the 1998 NIH report on obesity [13], twenty-four RCT articles were considered for the evaluation of the effects of physical activity on weight loss. The frequency of exercise varied from 3 to 7 sessions/week, and the duration ranged from 30 to 60 minutes, at an intensity to elicit a heart rate from 60 to 85 of the individual's estimated maximum heart rate, corresponding on average to 70% of maximum aerobic capacity ( $VO_{2\max}$ ). The report concludes that physical activity is recommended as part of a comprehensive weight loss therapy and weight maintenance program for several reasons having a variable category of evidence (Table 1).

**2.2. Exercise and Weight Loss Maintenance.** Weight loss maintenance has not been systematically examined by the

NIH report [13], but the report of the American College of Sports Medicine indicates that progressively increasing exercise to 200–300 minutes (3.3–5 hours) of exercise per week facilitates the long-term maintenance of weight loss [14]. Higher targets might be easily achievable by overweight people and might thus be more beneficial for long-term weight loss.

Data from the NWCR indicate that successful weight maintainers report higher levels of physical activity (on average 2800 kcal/wk) than the traditional recommended physical activity target (1000 kcal/wk) for weight control [15]. This amount seems to be a reasonable target to prevent or reduce weight regain [16]; in the NWCR, a decrease in physical activity below this target (equal to 60–90 min/day of moderate-intensity physical activity) was a predictor of weight regain over time [15]. A more recent analysis of the registry confirmed these results [17]: NWCR participants were confirmed to be an extremely physically active group and the level of activity when entering the registry was related to the magnitude but not the duration of weight loss. However, the amount of activity was extremely variable, and no single recommendation for the optimum amount of physical activity for weight loss maintenance could be developed [16].

The need of high levels of physical activity to maintain body weight has been confirmed by a randomized study [18]. After 18 months, the participants allocated to intense activity (approx. 2500 kcal/wk of exercise) had a better weight loss maintenance than those allocated to moderate levels of activity, and maintained a 50% larger weight loss. The study,

TABLE 2: Main reasons for not engaging in physical activity reported by obese subjects during group sessions in our Unit, and possible strategies to increase motivation and adherence.

Reasons for not exercising	Barriers	Strategies to increase adherence
“I would like to exercise, but I feel immediately tired and breathless, and my knees hurt”	Low fitness, pain	Exercising with individuals having the same limits, to reduce the intensity of exercise
“I do not like exercising, it is boring”	Boredom, lack of stimuli	Planning enjoyable activities or amusing exercising (e.g., group dancing or walking)
“I do not like exercising alone, but when I go walking with friends I realize that I slow down the group, which makes me feel inadequate”	Comparison with other individuals	Exercising with subjects having similar problems, in order to avoid competition
“Exercising in a gym or a swimming pool or even walking in a public garden makes me feel ashamed, observed, judged, mocked at”	Body image dissatisfaction	Arranging a protected environment, and specific courses (gym or swimming pool) for obese persons
“I’d like to exercise, but I have no time. Back from work, I am too tired and I have to take care of my family”	Time constraints	Reorganizing daily activities fitting exercise as a priority. Turning everyday activities into exercise (using stairs, walking to work, etc.)
“The weather was horrible; I had to stay at home”	Weather constraint	Planning short walk in small groups; reducing objectives but maintaining change and adherence
“I feel so bad when I exercise, that I feel as if I am going to die”	Death fear	Increasing goals very slowly, to avoid any sense of breathlessness

Most patients report difficulties in engaging in physical activity and in the maintenance of behavior changes. In general, patients underline the importance of low goal setting, new stimuli, social support, and long-term contact with therapists.

however, raised two important issues of concern. First, the injury rate was consistently greater in the group randomized to the high-intensity activity program [8], and injuries may be a relevant cause of attrition. Second, despite intense activity, the rate of weight loss progressively reduces and a modest weight regain might also be observed. This might be an additional cause of reduced self-efficacy and attrition.

In summary, data from the literature support the hypothesis that weight loss and weight loss maintenance are regulated by the total energy expenditure of the activity rather than from the intensity of activity [19].

**2.3. Benefits of Exercise in the Clinical Setting.** The benefits of physical activity largely outweigh weight loss. Both walking and vigorous exercise are associated with substantial reductions in the incidence of cardiovascular events [20], and these advantages are maintained also among subjects among groups at high cardiovascular risk [21, 22]. An extensive meta-analysis showed that both adiposity, measured by BMI or by waist circumference, and physical inactivity are important determinants of mortality risk [23]. Physical activity may protect from diabetes and the metabolic syndrome. In several studies, physical exercise has shown a protective effect against metabolic diseases via decreased body weight and visceral fat accumulation, HDL cholesterol levels, reduced triglycerides, and blood pressure [24, 25]. These last changes may also be independent of weight loss. In a population-based cohort, high-risk men regularly engaging in vigorous leisure-time physical activity (LTPA) or with high cardiorespiratory fitness were less likely to develop the metabolic syndrome than sedentary men [26]. Data were confirmed in aged individuals [27].

In a post-hoc analysis of the Finnish Diabetes Prevention Study, a randomized controlled trial of lifestyle changes

including diet, weight loss, and physical activity in the prevention of type 2 diabetes in subjects at risk, individuals who increased moderate-to-vigorous or strenuous, structured physical activity were less likely to develop diabetes during the 4.1-year follow-up period [28]. Low-intensity LTPA and walking also conferred benefits, suggesting that the incidence of type 2 diabetes may also be modulated in high-risk individuals. At the end of the study, participants who were still free of diabetes were further followed up for a median of 3 years, and the incidence of diabetes remained lower in the intervention group. The risk reduction was related to the success in achieving the intervention goals of weight loss, reduced intake of total and saturated fat and increased intake of dietary fiber, and increased physical activity [29].

Similar data were reported in the US Diabetes Prevention Program, where the prevention of diabetes was achieved by healthy diet, weight control, and activity goals. In the intensive group, the activity goal (150 min/wk) was initially achieved by 74% of participants and by 67% in the long-term, and meeting activity goals was associated with sustained weight loss [30].

### 3. The Problem of Adherence

The incorporation of exercise as a consistent lifestyle behavior is not easy for many obese individuals because of poor exercise tolerance and enjoyment [7]. Several factors create obstacles to physical activity of obese and normal weight individuals, such as low motivational status, self-efficacy, negative learning history with exercising, lack of coping skills, and aversive environmental characteristics such as reduced access to physical activity facilities, high costs of training programs, low social and cultural support, and

time barriers [8]. Making individuals with obesity move and improving adherence to exercise is a critical challenge: hence the importance to understand the psychological determinants of exercise behavior. We report in Table 2 the main reasons for not engaging in physical activity reported by obese subjects during group sessions in our Unit, and the possible solutions to increase motivation and adherence. Most patients feel that these strategies may be relevant to start physical exercise, but do not guarantee maintenance. This consideration stresses the importance of low goal setting, new stimuli, social support, and long-term contact with therapists (see below).

*3.1. Psychological Predictors of Physical Activity.* Existing theories and research on the psychological predictors of success in exercise suggested that self-efficacy, the stage of change, expectations, and psychological well-being may be particularly important. However, they also suggested conflicting hypotheses about the ways in which these factors impact upon adherence.

The stage of change theory [31] suggests that the take-up and maintenance of health behaviors, such as exercise, follows a number of stages, namely, precontemplation, contemplation, preparation, action, and maintenance [32]. The theory suggests that subjects in the contemplation or precontemplation stages (who have limited or no thought to exercising) will never adhere to exercise counseling, compared with subjects in the preparation stage (who already intended to exercise and may have given it considerable thought).

Self-efficacy, one of the most consistent predictors of exercise adherence [33], is related to stage of change [34, 35]. Self-efficacy refers to the extent to which an individual believes they are capable of carrying out a behavioral change, and increasing self-efficacy will lead to increased effort and time being devoted to the task [36]. In the context of the stage of change theory, precontemplators are expected to show lower self-efficacy than contemplators, whereas those in the maintenance stage show the highest [34]. Self-efficacy may also predict progression between stages [37].

On the other hand, too ambitious expectations may preclude success. This theory is supported by studies showing that subjects scoring high on a measure of expectancy-value (but low on self-efficacy) were most likely to give up [38, 39]. Both high expectancies of change and violation of these expectancies predicted lack of adherence in previously sedentary women who started a structured physical activity program [39].

The initial psychological well-being may also be relevant to adherence. It is very likely that poor psychological well-being might influence people's ability to adhere to behavioral changes. The energy available for self-change efforts is probably limited, and mental stress may decrease the available energy [40]. In addition, poor psychological well-being may have an impact on confidence and self-efficacy, favoring attrition. In a study measuring the comprehensive role of participant expectation, self-efficacy, stage of change, and psychological well-being in adherence to an exercise program, subjects who completed the course had lower

expectations of change and came closer to achieving expected changes than those who dropped out [41]. While self-efficacy improved in completers, it tended to deteriorate in dropouts. This finding suggests that overly optimistic expectations may lead to disappointment and attrition in physical activity programs. Interventions to ensure realistic expectations might increase success and prevent potential negative effects of failure.

In the US Diabetes Prevention Program [42], greater readiness for change in physical activity level, higher exercise self-efficacy, and lower perceived stress, depression, and anxiety scores correlated with higher levels of baseline activity and maintenance of activity levels at 1 year and at end of study. These findings may help determine which patients are most likely to increase physical activity levels in lifestyle intervention programs.

#### **4. Cognitive Behavioral Strategies to Engage Patients in Increasing the Level of Exercise**

Most physicians are well aware of the importance of a healthy diet and exercise to promote weight loss and weight loss maintenance and know the optimal target of physical activity as suggested by National and International Agencies and Guidelines, but a minority have received adequate training during their university curricula to establish an effective communication to promote lifestyle change.

*4.1. Key Principles to Enhance the Motivation to Change.* Similar to other motivational enhancement approaches [43], cognitive behavior therapy adopts key principles to enhance the motivation of patients to address behavioral changes [44]. First, it conceptualizes motivation as a dynamic entity waxing and waning as a function of shifting personal, cognitive, behavioral, and environmental determinants. Second, it adopts a collaborative therapeutic style as opposed to a confrontational approach. Third, it validates patients' experience within the framework of a balance between acceptance and change, firmness, and empathy. Fourth, it uses the functional analysis of the pros and cons of a belief or behavior because change seems facilitated by communicating in a way that elicits the person's own reasons for the advantages of change. Fifth, it does not address resistance with confrontation, but with a collaborative evaluation of the variables maintaining the dysfunctional behavior. Sixth, it supports patients' self-efficacy.

Following these key principles, clinicians should validate the experience of the patients by acknowledging with them the perceived positive effect of exercising and (if present) the ambivalence to change. At the same time, clinicians should inform patients on the negative aspects of sedentary life and the benefits of engaging in healthy exercising.

*4.2. Educating Patients about the Benefit of Exercising.* The first step is educating patients about the benefit of exercising and the need to increase the level of physical activity for long-term weight control. The principal pieces of information that patients should know on the benefit of exercising are as follows.

- (i) *Physical activity may help preserve fat-free mass during weight loss.* About 75% of weight lost by dieting is composed by fat and 25% by fat-free mass (FFM) [45]; adding a physical activity program to dietary therapy may reduce the loss of FFM [45, 46].
- (ii) *Physical activity increases energy expenditure.* The amount of energy expenditure depends on the intensity, duration of the activity, and on the muscle group involvement. The increase in energy consumption associated with activity occurs primarily during the activity itself, but there is also a short-lived postexercise increase in metabolic rate [47].
- (iii) *Physical activity alone results in minimal weight loss.* Exercise alone, without any dietary intervention, produces minimal weight loss (i.e., an average 2 kg decrease in body weight compared with a control group) [18, 48, 49].
- (iv) *Physical activity generally does not increase short-term diet-induced weight loss.* Most studies found that adding exercise to dietary therapy does not significantly increase short-term weight loss compared with dietary therapy alone [50–53].
- (v) *Physical activity plays an important role in the maintenance of weight lost.* Cross-sectional studies and retrospective analyses of prospective trials found that successful long-term weight loss is associated with the maintenance of regular exercise [53–55].
- (vi) *Considerable physical activity is necessary for weight loss maintenance.* The amount of physical activity required to reduce the rate of weight regain seems to be larger (e.g., 2500 kcal/wk = walking 75 min/day) than the moderate-intensity exercise recommended by the American College of Sports Medicine and the Centers for Disease Control and Prevention to maintain good health (1000 kcal/wk = walking 30 min/day) [18, 56].
- (vii) *Exercising at home improves adherence to a physical activity.* Data from prospective randomized trials have shown that long-term adherence to a walking program is better in participants assigned to walk at home compared with those who were randomized to a supervised on-site program [57, 58]. A home-based physical activity program is associated with greater long-term weight loss than group-based programs [58], where barriers to exercising (e.g., cost and time constraints) may reduce attendance.
- (viii) *Short bouts of exercise might improve the adherence to programmed activity.* A randomized control trial showed that women with obesity assigned to four short (10-minute) bouts of exercise 5 days weekly had greater adherence to exercise and weight loss than those assigned to one long (40-minute) bout of exercise 5 days weekly, for 20 weeks [59], although larger studies did not replicate the results [19, 57].
- (ix) *Weight maintenance can be achieved with either programmed or lifestyle activity.* Increasing daily lifestyle

activities is as effective as a structured aerobic exercise program in maintaining long-term weight loss [60].

- (x) *Aerobic fitness, independent of body fat, is associated with health gains.* Irrespective of body fat or weight loss, aerobic fitness is associated with lower cardiovascular mortality [61] and a decreased risk of diabetes [62].

**4.3. Creating a “Pros and Cons to Change” Table.** The second step involves creating a “pros and cons to change” table. Patients should be asked to evaluate their reasons for and against adopting an active lifestyle. Clinicians should emphasize that change is a necessary step to achieve a long-term weight control and to improve the physical and psychosocial negative effects of obesity. It is advised to begin by asking patients to list the cons of changing, considering whether sedentary life provides them with something positive that they are afraid to lose. Then patients are asked to evaluate in detail the pros of changing their lifestyle. In doing this, clinicians should urge patients to reflect on the short- and long-term effects of changing activity levels on health, psychological function, and relationships. The list of pros and cons should be put on a table and discussed in detail. During this discussion, clinicians should urge patients to focus on the long-term goals and not just on the present. Every reason for change should be reinforced. It is also important to analyze the cons of changing, helping patients reach the conclusion that the positive aspects of increasing the level of activity are attained in the long term, and are always associated with positive gains.

The importance of discussing with the patients the pros and cons of lifestyle changes is proved. In a recent study, adding motivational interviewing (i.e., a brief intervention approach eliciting the patients’ own reasons and arguments for change) to a behavioral weight control program improves weight loss outcomes and glycemic control in specific groups of overweight women with type 2 diabetes [63].

**4.4. Involving Actively Patients in the Decision to Change.** The final step is to help patients reach the conclusion that adopting an active lifestyle will be a positive opportunity for a new and healthy life and long-term weight control. A key aspect of engagement is to stimulate patients to make spontaneously statements such as “If I start exercising I will ...” because it is the sign that they see the need to change their lifestyle. In these cases, clinicians should make a confirmatory statement such as “I realize that you have decided to try and change your exercise habits”. At this point, clinicians should actively suggest that patients should try to change.

## 5. Cognitive Behavioral Strategies to Increase Patients’ Adherence to Exercise

In the last 20 years, several cognitive behavioral strategies have been found to improve the patients’ adherence to exercise, and should be included in the treatment of obesity.

**5.1. Assessing Patients' Activity Levels.** An initial assessment is needed to determine the patient's current activity levels. Clinicians should ask patients how they judge their actual level of physical activity, and if they believe that it is adequate to lose or maintaining body weight. If, as usual, patients report being sedentary, clinicians should ask the reasons of their sedentary life, and if there are barriers to exercise (e.g., arthritis).

The presence of medical comorbidities (e.g., dyslipidemia, hypertension hyperinsulinemia, metabolic syndrome, and diabetes) may require additional medical evaluations, including an exercise testing and/or appropriate medical supervision during exercise.

**5.2. Tailoring Activity Goals to Individual Patients.** Clinicians should evaluate which type of activity is physically possible for patients, and the barriers that can prevent a successful increase in activity. Accordingly, they should assist patients in developing a physical activity plan, based on the initial assessment.

Physical activity should be started at a low level and gradually increased to a goal of 150–200 minutes per week in selected patients [65]. Compliance to exercise can be enhanced by increasing lifestyle activities (e.g., climbing stairs, gardening, and walking the dog), developing an appropriate home-based exercise program, and considering short bouts rather than long bouts of activity for patients who “can't find the time to exercise”. There are many practical recommendations for physical exercise in weight loss programs [64], as outlined below. Note that the aim of behavior therapy is to provide patients cognitive and behavioral skills to modify their lifestyle. Accordingly, these recommendations should not be intended as prescriptions, but should be tailored on patients' preferences.

- (i) Engage in moderate-to-vigorous exercise for at least 60 minutes on most days (at least 5 days per week).
- (ii) Walking may be the preferred exercise (unstructured exercise may be included in routine daily activities).
- (iii) Check the baseline number of steps by a pedometer, then add 500 steps at 3-day intervals to a target value of 10,000–12,000 steps per day.
- (iv) Jogging (20–40 min/day), biking or swimming (45–60 min/day) may replace walking.
- (v) Physical exercise is intended to produce a calorie deficit of at least 400 kcal/day, favoring weight loss, maintaining muscle mass and preventing weight cycling.

Clinicians should always keep in mind that obesity *per se* is an important barrier to physical activity, as it poses several unique challenges to the obese individual [66]. The most typical barriers reported by patients are “being too fat, shy or embarrassed to exercise”, “being too lazy or unmotivated”, “having an injury or disability” or “being not the sporty type” [67]. Women with obesity reported lower pleasure ratings during exercise of increasing intensity and lower energy scores immediately after the exercise than nonobese

women [68]. These two factors may partly explain the lower level of participation to exercise of obese individuals. A careful assessment of barriers to physical activity caused by obesity *per se* is mandatory in all cases and exercise prescription must be changed accordingly (e.g., switching to non-weight-bearing exercise, or to lower-intensity exercise).

**5.3. Self-Monitoring.** Self-monitoring (of energy intake and expenditure) is the cornerstone of the behavioral treatment of obesity. The larger the use of self-monitoring, the larger the amount of weight loss [69]. Monitoring raises patients' awareness of their exercise habits and helps them identify ways to maximize their energy deficit. Physical activity can be recorded in a monitoring record in minutes (of programmed activity) and/or steps (of lifestyle activity), using a pedometer [70]. Patients interested in having a more precise measurement of their daily caloric expenditure may use an accelerometer, that measures total energy expenditure, the energy expenditure in physical activity, the duration and the levels (METs) of physical activity and sleep time. Patients may also benefit from recording activities, moods, and thoughts associated with exercising. This information may help identify obstacles to exercising. Self-monitoring records can also be used to provide information to identify activity contingencies that can be targeted for intervention [70].

**5.4. Stimulus Control.** These strategies are based on the principles of classical and operant conditioning. The main focus is to modify the external environment to make it more conducive to making choices that support exercising. Patients should be instructed not only to remove triggers of inactivity, but also to increase positive cues for healthy activity (e.g., lay out exercise clothes before going to bed). Stimulus control may also be used to reinforce the adherence to exercise by establishing a reward system (e.g., encouraging patients to set weekly behavioral goals and to reward themselves in case of achievement, not through food or inactivity)[70].

The efficacy of stimulus control strategies has been demonstrated since the late 70s, when behavioral weight loss programs produced a weight loss of approximately 4.5 kg over 10 weeks without the prescription of any specific caloric intake or energy expenditure [71].

**5.5. Involving Significant Others.** Social support is a key ingredient for behavioral change. Data show that social support is considered to be an important aid for weight maintenance [72, 73], and significant others may play an important role in encouraging patients to increase daily physical activity and to reinforce the changes. With the consent of patients, clinicians should involve significant others in the treatment in order to create the optimum environment for patients' change.

Significant others should be educated about obesity, weight management, and physical activity. They also should be actively involved in exploring how to help patients develop and maintain an active lifestyle. The needs vary from patient to patient; the general advice to give to significant others

include creating a relaxed environment, reinforcing positive behaviors, adopting a positive attitude, exercising together and accepting patients' setbacks.

*5.6. Building the Mindset of an Active Lifestyle.* Cognitive processes are involved in the maintenance of complex behaviors, such as developing an active lifestyle. The role of cognitive processes implicated in weight loss and weight maintenance has been extensively evaluated in the QUOVADIS study, a large observational study on quality of life in obese patients seeking treatments at 25 medical centers certified by the Italian Health Service for the treatment of obesity [74]. The study provided three main results. First, drop-out was associated with higher weight loss expectancies [75]. Second, the amount of weight loss was predicted by increased dietary restraint and reduced dietary disinhibition [76]. Third, a long-term weight maintenance (>3 years) was observed in patients satisfied with the results achieved, and confident to control their body weight without additional professional help [77], a construct similar to the concept of self-efficacy that is associated with greater adherence to physical therapy [78].

Cognitive strategies are scarcely used in standard behavior programs for weight control, and this may be one of the reasons for their limited effectiveness [79]. There is a need for adding new and more effective cognitive interventions to the standard strategies to help patients develop a mindset of long-term weight control, as follows.

(i) *Encourage patients to make a list of personal reasons to adopt an active lifestyle.* Clinicians should ask to review the list every day and when they feel in difficulties, in order to train the mind to focus on weight control and exercising.

(ii) *Set short-term goals and cognitive credits.* Goal setting is a key component of cognitive-behavior therapy for weight loss and has been shown to be effective in focusing the attention of participants toward behavior change [80]. Patients should be encouraged to set specific and quantifiable weekly goals (e.g., increasing 1,000 steps a week), which should be realistic and moderately challenging [70]. The achievement of these goals is generally associated with a sense of accomplishment, which is reinforcing and enhances self-efficacy [81]. Patients should learn how to use cognitive credits once they reach their activity goals using positive sentences towards themselves (e.g., "I've been good", "I'm doing great", "I have the ability to lose weight and to change into an active lifestyle"). The regular use of cognitive credits may help patients reduce their frustration associated with weight loss and strengthen their confidence of being able to control body weight and to maintain an active lifestyle.

(iii) *Address weight loss expectations and weight loss satisfaction.* The association between higher weight loss expectations and attrition indicates that the problem of weight loss goals should be addressed both in the initial interview and during the entire course of the treatment. However, encouraging participants seek only modest initial weight losses does not facilitate weight maintenance, and produces a lower weight loss than standard behavior weight loss treatments [82]. At the beginning of treatment, it is more useful to focus patients on weekly weight loss and to

detect and address promptly any warning sign of weight loss dissatisfaction, thus minimizing the risk of attrition [75]. In our clinical experience, unrealistic weight loss expectations may be changed later in the course of treatment, when patients have reached some intermediate goals, and the rate of weight loss is declining. Specific strategies to change weight goals have been recently described in the modern cognitive behavioral treatments of obesity [83]. A crucial aspect favoring the modification of unrealistic weight goals is the development of a trusting and collaborative relationship between the clinician and the patient [75]. This is also a key factor in avoiding the sense of abandonment that patients report as one of the main reason of attrition [84].

(iv) *Address obstacles with problem solving.* Clinicians should train patients in using problem solving to address problems that hinder exercise adherence. The typical problem-solving approach includes 5 steps [85]. Step 1 encourages patients to describe a problem (i.e., an obstacle to exercising) in great detail, and the chain of events (that is, situations) that preceded the problem. Step 2 helps patients brainstorm any possible solution. During step 3, patients are encouraged to list the pros and cons for each potential solution. In step 4, patients should choose the best option on the basis of the previous analyses, to be implemented for a fixed amount of time. Finally, during step 5, the patients evaluate the results achieved. If the solution failed, the process should be repeated. Specifically, once patients identify a problem, they should write "Problem" in their monitoring record and then turn the record over and address it by writing out the five problem-solving steps. Mental, unwritten problem-solving is much less effective. Support to the importance of incorporating problems solving in the management of obesity comes from a study in which the participants who completed cognitive therapy coupled with problem solving had significantly greater long-term weight loss than participants who completed standard behavior therapy [86].

(v) *Cognitive restructuring.* Through this technique, patients learn how much thoughts influence both mood and behaviors, and that a more rational and functional way of thinking can help improve adherence to lifestyle programs [70]. Cognitive restructuring is used to modify cognitive biases (all-or-nothing thinking) about weight regulation and to correct unrealistic weight loss expectations.

*5.7. Responding to Nonadherence.* Long-term adherence to an active life-style and weight control can be extremely difficult because of a complex combination of biological, environmental, and psychological pressures. Clinicians should congratulate the patients for every small successes they achieve, and should never criticize failures [87]. Criticism may produce guilt and loss of self-confidence, leading to attrition. An unconditional acceptance of the patients' behavior and a problem-solving approach to address barriers will preserve the clinician-patient relationship. This approach will also help patients understand that the long-term success in weight management is related to a set of skills rather than simply to willpower.

## 6. Conclusions

The development of new methods to facilitate patients' increased physical activity, and the long-term maintenance of physical activity is fundamental for the maintenance of weight loss and for reducing the health risk of individuals with obesity.

To date many strategies may be used to improve adherence. Data from literature indicate that patients who exercise at home, as compared with on-site (i.e., health club or clinic), have better adherence to exercise and/or lose more weight [58, 88]. Similarly, multiple short bouts of activity (i.e., 10 minutes) are at least as effective in facilitating exercise adherence and weight loss, as a single long bout (i.e., 40 minutes) [57, 59]. Short bouts give more opportunity to individuals to fit exercise into a busy day, such as using stairs rather than escalators or walking rather than driving the car. Lifestyle intervention is as effective as the traditional structured exercise for improving cardiorespiratory fitness and weight control [60, 89] and may be a good alternative for those who do not like to practice sport. Independent of weight control, fit-fat people have a lower incidence of cardiovascular mortality [61] and a decreased risk of developing diabetes [62].

Unfortunately, weight loss maintenance can only be achieved with an activity-related energy expenditure of approximately 1,500–2,500 kcal/wk, as compared with the 1,000 kcal/wk traditional target of behavioral programs [18]. For most individuals with obesity, it is difficult to achieve such high levels of physical activity. Therefore, it is advisable to encourage subjects to start with activity goals they can achieve rather than with very ambitious goals they are likely to fail, and to increase gradually the daily activity levels.

In summary, we need to move from the traditional prescriptive approach to diet and exercising, towards a more multidisciplinary intervention aimed at increasing the adherence to physical activity. The key role of cognitive processes in the failure/success in weight loss and maintenance [74–77] suggests that new cognitive procedures and strategies should be included in the traditional behavioral treatment of obesity, in order to help patients build a mindset of long-term weight control.

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## Research Article

# Low Fat Loss Response after Medium-Term Supervised Exercise in Obese Is Associated with Exercise-Induced Increase in Food Reward

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**Objective.** To examine exercise-induced changes in the reward value of food during medium-term supervised exercise in obese individuals. **Subjects/Methods.** The study was a 12-week supervised exercise intervention prescribed to expend 500 kcal/day, 5 d/week. 34 sedentary obese males and females were identified as responders (R) or non-responders (NR) to the intervention according to changes in body composition relative to measured energy expended during exercise. Food reward (ratings of liking and wanting, and relative preference by forced choice pairs) for an array of food images was assessed before and after an acute exercise bout. **Results.** 20 responders and 14 non-responders were identified. R lost  $5.2 \text{ kg} \pm 2.4$  of total fat mass and NR lost  $1.7 \text{ kg} \pm 1.4$ . After acute exercise, liking for all foods increased in NR compared to no change in R. Furthermore, NR showed an increase in wanting and relative preference for high-fat sweet foods. These differences were independent of 12-weeks regular exercise and weight loss. **Conclusion.** Individuals who showed an immediate post-exercise increase in liking and increased wanting and preference for high-fat sweet foods displayed a smaller reduction in fat mass with exercise. For some individuals, exercise increases the reward value of food and diminishes the impact of exercise on fat loss.

## 1. Introduction

The capacity for exercise to reduce overweight varies considerably between individuals [1–4]. It has been demonstrated that some individuals experience a lower than predicted fat loss despite >90% adherence to 12 weeks of daily supervised exercise [3]. Characterising the determinants of this variability—particularly for the less successful individuals—could help to design more appropriate and effective weight loss strategies. Previously, we reported that weight loss during a program of regular moderate intensity exercise was partly determined by differences in hunger levels experienced during the day [5]. One additional cause of the variability in weight loss could be exercise-induced alterations in the reward value of foods with particular sensory and/or

macronutrient profiles [6]. The extent that changes in food reward go on to influence food choice may then determine the degree of compensatory eating [7, 8]. This relationship could depend in part on eating behaviour traits of the population studied such as restrained or disinhibited eating styles [9–12], or it could be influenced by metabolic processes such as substrate oxidation or secretion of gastrointestinal hormones [13–16]. It has been hypothesised that exercise causes a neurochemical response that has a sensitizing action on brain reward systems (e.g., [17]). Another possibility is the deliberate choice of highly palatable, energy-dense foods (e.g., fatty or sweet tasting “treats”) to reward virtuous behavior or regulate changes in mood [18] or stress [19].

Recently, we found in lean individuals that enhanced implicit wanting for images of food after exercise could

predict those who also increased their food intake compared to those whose food intake did not change [20]. However, insufficient data are available on the extent to which exercise-induced changes in food reward influence energy intake through macronutrient selection [6], and there are no data on the effect of exercise on food reward when exercise is continued over many weeks. Furthermore, it is unknown whether the reward value of food has a role in the effect of medium-term exercise on energy balance and weight loss in overweight and obese individuals. Therefore, the aim of this study was to examine exercise-induced changes in the reward value of food during a medium term (12 weeks), fixed volume schedule of supervised exercise in sedentary overweight and obese individuals. Participants were assessed using a validated computerised procedure [21, 22] that measured components of reward (liking, wanting, and food preference) for an array of photographic food images that varied in taste and fat content, before and after an acute bout of exercise. This procedure was repeated at baseline and week 12 of the intervention.

We predicted that acute exercise would cause an increase in liking, wanting, and preference for high-fat food at the beginning of the intervention. Furthermore, we predicted that after 12 weeks of regular exercise, these effects would be attenuated in those who met or exceeded the predicted reduction in fat mass (Responders) compared to those who compensated for the exercise and experienced a lower than predicted reduction in fat mass (Nonresponders).

## 2. Methods

**2.1. Subjects and Recruitment.** Forty sedentary overweight and obese but otherwise healthy volunteers (13 males) with mean body mass index = 31.3 ( $\pm 3.8$  kg/m<sup>2</sup>) and age = 39.6 ( $\pm 10.5$  years) participated in this study. Participants were recruited from those who enrolled on a 12-week exercise programme conducted at the Human Appetite Research Unit, University of Leeds [23]. Therefore, these participants formed a subset of individuals who were taking part in a larger study. The data reported in this study have not been published previously. Participants gave their written consent to take part in the study, and ethical approval was obtained from the Institute of Psychological Sciences Ethics committee.

**2.2. Experimental Design.** The study examined the acute effects of a bout of exercise on the reward value of food at two time points immediately before and following a 12-week schedule of regular supervised exercise. Participants provided reward measures for 20 photographic images of food presented via computer immediately before and then immediately following a supervised exercise session. The food images varied in taste and macronutrient properties and were categorised according to sensory domain (sweet/non-sweet) and fat/carbohydrate content (high or low). Participants were identified as “responders” or “Nonresponders” to the 12-week intervention according to their final net energy balance which was based on their actual measured changes

in body composition relative to the gross exercise-induced energy expenditure.

**2.3. Exercise Protocol.** The exercise protocol used in this study has been described in detail elsewhere [5, 23]. Participants underwent a 12-week exercise programme that was individually prescribed to expend 500 kcal per session, 5 days per week. Therefore, a total volume of 30,000 kcal energy expenditure was prescribed. All exercise sessions were supervised in the research unit and participants wore a heart rate monitor during each session. The exercise prescription was adjusted for each participant every 4 weeks using submaximal VO<sub>2max</sub> tests during which indirect calorimetry was performed. This allowed the exercise prescription to be modified to account for changes in cardiovascular fitness and body weight. The acute exercise bout fixed was intensity submaximal exercise (70% heart rate max) conducted on a stationary exercise bike (Sapilo, Italy). Water was provided at the beginning and end of the session. Energy expenditure of each exercise bout was calculated by comparing heart rate and duration of the session against expenditure values from indirect calorimetry.

**2.4. Body Composition.** Body weight and body composition (lean and fat mass) were measured using air displacement plethysmography (BodPod, Life Measurement Incorporated, Concord, CA). ADP has been validated against dual energy X-ray absorptiometry (DXA) and is more suitable for frequent repeated measures research [24–27]. Height was measured using a stadiometer (Seca, Leicester, UK).

**2.5. Measurement of Reward Value of Food.** The reward value of food was measured using a computer-based behavioural procedure called the Leeds Food Preference Questionnaire (LFPQ) [21, 22]. The LFPQ has demonstrated good test-retest reliability, both on immediate repetition and after one week (typical  $r = .61-.95$ ). The procedure has proven sensitive to acute dietary manipulations [28, 29] and single bouts of exercise in nonobese women [20]. Concurrent validity of the LFPQ with other behavioural paradigms of food reward (i.e., using progressive ratio schedules of reinforcement) is satisfactory [30]. In this measure, an array of 20 photographic food images was used within two behavioural tasks administered using experiment generator software (E-prime v.1.2, Psychology Software Tools, ND). The foods were chosen to vary along the dimensions of sensory domain (sweet/non-sweet taste) and fat/carbohydrate content (high or low by percentage). Half the foods contained >45% energy as fat while the other half comprised <20%. These foods were further divided into sweet tasting (i.e., dessert foods) and non-sweet tasting (i.e., salty foods). The foods were controlled between categories for energy and protein content. All foods had been validated in a previous study and rated using 7-point scales on their perceived familiarity, typicality of presentation (most to least typically encountered), and perceived macronutrient and taste properties [22]. See Table 1 for details of the food images used in the LFPQ. Food images were presented individually or in pairs

TABLE 1: Photographic food images and food categories used in the procedure.

High-fat non-sweet (HFNS)	Low-fat non-sweet (LFNS)	High-fat sweet (HFSW)	Low-fat sweet (LFSW)
Salted peanuts	Boiled potatoes	Cream cake	Fruit salad
Potato chips	Bread roll	Jelly doughnut	Fruit candies
Mixed olives	Pilau rice	Milk chocolate	Marshmallows
French fries	Pasta in sauce	Shortbread	Jelly babies
Swiss cheese	Crackers	Cream slice	Rich tea biscuits

on a 17" monitor and measured 150 × 100 mm<sup>2</sup>. Participants responses to the foods in the array were pooled according to categories of high-fat non-sweet (HFNS), low-fat non-sweet (LFNS), high-fat sweet (HFSW), and low-fat non-sweet (LFNS). Three separate measures were derived from participants' evaluation of the foods.

**2.6. Expected Liking.** Participants were prompted with the question "How pleasant would it be to taste this food now?". Expected liking measured the conscious feeling of pleasure expected from tasting each food. Foods were rated individually according to a 100 mm visual analogue scale anchored at each end by the statements "not at all" and "extremely". Scores for each food category were aggregated from the individual ratings with a possible range of 0–100.

**2.7. Explicit Wanting.** Using the same response format as expected liking, participants responded to the question "How much do you want some of this food now?". Explicit wanting measures the conscious desire for each food [21, 31]. Scores for each food category ranged from 0 to 100.

**2.8. Food Preference.** Relative preference for each food category was measured by a series of "forced choice" pairings of each food image with every alternative food in the array. Participants were presented with 150 such pairs and followed the written instruction in each trial to select the food they "most want to eat now". Foods were randomly presented on the left or right side of the screen and participants could choose between each pair by pressing the corresponding buttons. The number of choices made in each food category (possible range 0–75) was recorded.

**2.9. Statistics.** Data were prepared using Microsoft Excel and analysed using SPSS v.16 for Windows. Response to the intervention was assessed by calculating net energy balance from measured energy expenditure during the exercise compared to estimated energy flux from measured changes in body composition. We used the estimation that 1 kg loss of fat mass is equivalent to 9,540 kcal, and 1 kg loss of lean mass is equivalent to 1,100 kcal [32]. Therefore, participants who achieved a negative energy balance which matched or

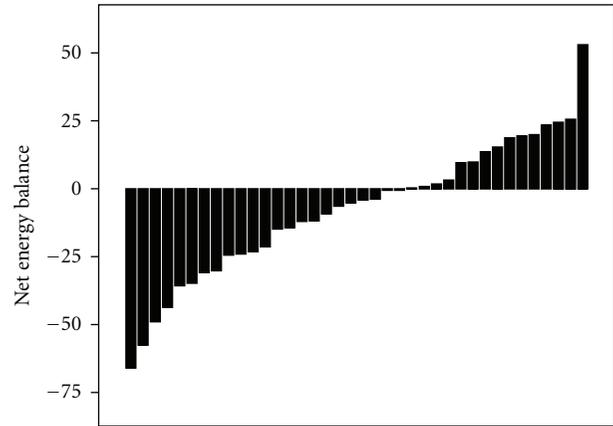


FIGURE 1: Individual variability in net energy balance after a prescribed volume of 12-week exercise ( $N = 34$ ). A value below zero (i.e., "Responder") indicates reduced body mass exceeding measured energy expenditure from the intervention. Values shown are for kcal in "000s".

exceeded predicted changes in body composition were identified as "Responders", while those whose actual weight loss was lower than the predicted were identified as "Nonresponders" (indicating a degree of energy compensation).  $2 \times 2$  mixed ANOVA were used to compare anthropometric values at baseline and week 12, within- and between-responder and non-responder groups. Changes in the reward value of food were analysed by separate 3-way mixed ANCOVA (Responder group \* intervention week \* food category) with baseline BMI as covariate. Interactions between intervention week, food category, and Responder group were verified by  $t$ -tests with Bonferroni correction to control for type I error.

### 3. Results

**3.1. Identification of Responders and Nonresponders.** Thirty six out of 40 participants successfully adhered to the 12-week intervention. Two participants had incomplete LFPQ data. Therefore, data for 34 participants were included in the analyses. The individual variability in energy balance at week 12 is shown in Figure 1. Based on these participants' net energy balance, we identified 20 Responders (6 males) and 14 Nonresponders (7 males) to the intervention. Measured energy expenditure from exercise did not differ significantly between groups ( $P = .40$ ). There was a trend for Responders to have a greater BMI at baseline compared to Nonresponders ( $P < .06$ ). Mean duration of the acute exercise bout was greater at baseline compared to week 12 ( $P < .001$ ) and mean verified expenditure of the bout was less at baseline than week 12 ( $P < .01$ ). There were no differences in duration or expenditure between Responders and Nonresponders. The characteristics of these groups are presented in Table 2.

R experienced a greater negative energy balance compared with NR which was reflected in their greater fat mass loss. There were no differences in other variables including starting weight, change in lean mass, duration of exercise sessions, or net energy expenditure from exercise.

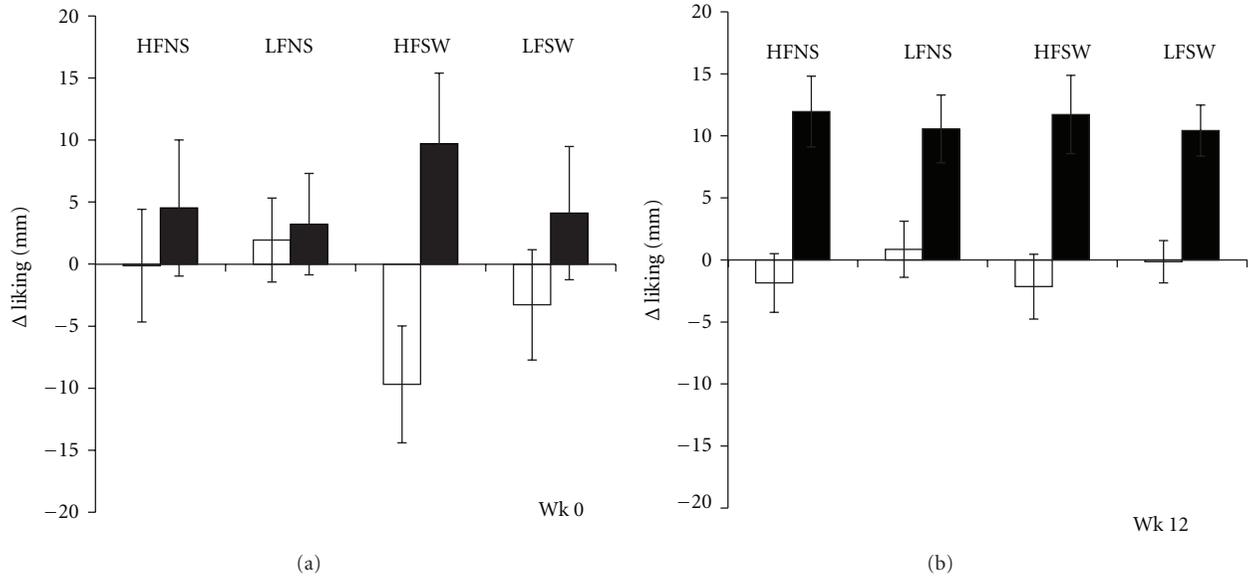


FIGURE 2: Acute changes in liking for food categories measured before and after a single bout of exercise in Responders ( ) and Nonresponders ( ). HF: high fat, LF: low fat, NS: non-sweet, SW: sweet.

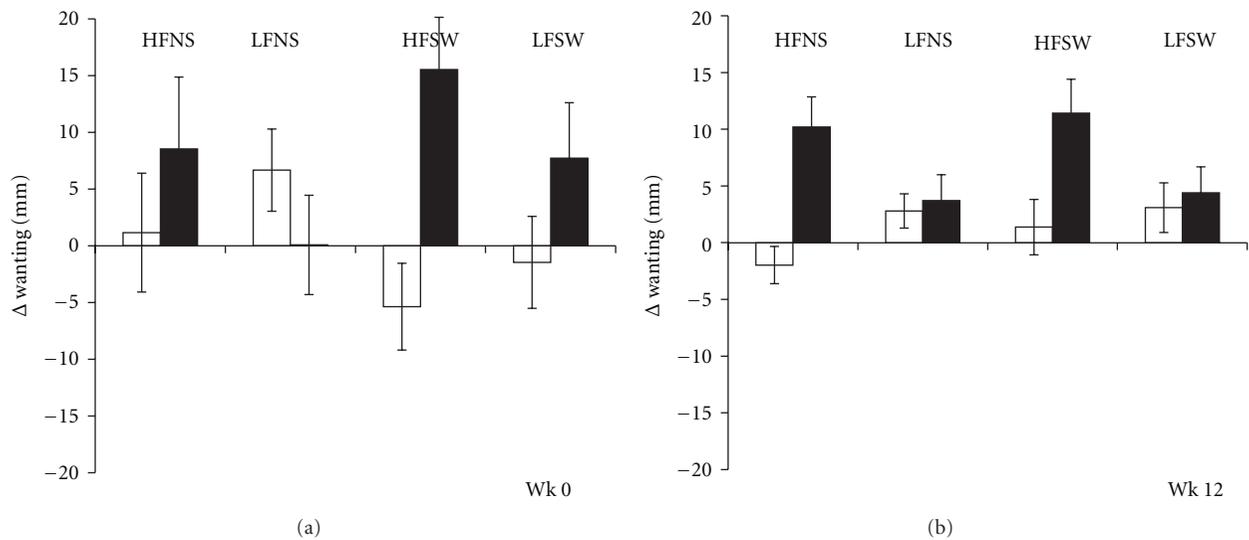


FIGURE 3: Acute changes in explicit wanting for food categories measured before and after a single bout of exercise in Responders ( ) and Nonresponders ( ). HF: high fat, LF: low fat, NS: non-sweet, SW: sweet.

3.2. *Hedonic Evaluation of Food Images (Leeds Food Preference Questionnaire)*. Exercise induced changes on the LFPQ are shown for Responders and Nonresponders in Table 3. ANCOVA revealed no effects of baseline BMI or BMI\*food category interactions on liking, wanting, or food preference.

3.3. *Expected Liking*. There was a significant main effect of Responder group on changes in liking [ $F(1,31) = 12.2, P < .001$ ]. Ratings of liking increased after exercise in NR compared to R. This finding was similar across all food categories and at weeks 0 and 12. That is, the increased liking

was independent of food category and after 12 weeks of exercise-induced increase in EE.

3.4. *Explicit Wanting*. Similar to liking, there was a main effect of Responder group on explicit wanting [ $F(1,31) = 6.6, P < .05$ ]. In addition, there was a significant interaction between responder group and food category on changes in explicit wanting [ $F(3,93) = 6.9, P < .0001$ ]. NR showed a specific increase in explicit wanting for high-fat sweet foods ( $P < .01$ ). This effect appeared more pronounced at week 0 (see Figure 3), however, the three-way interaction did not reach significance [ $F(3,93) = 2.1, P = .10$ ]. The trend for

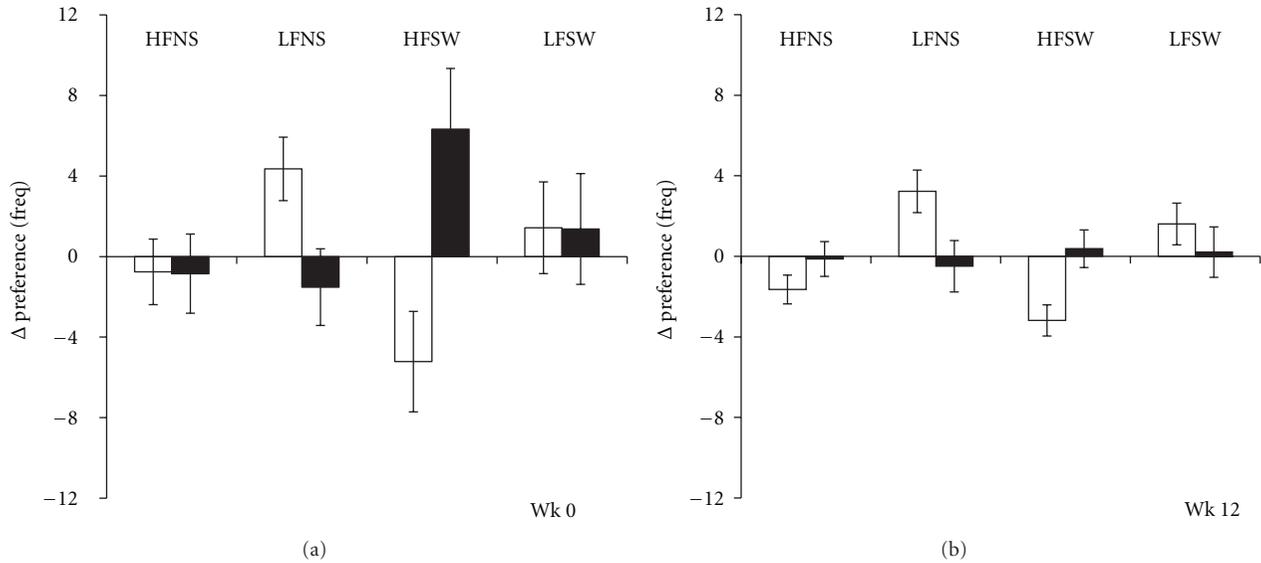


FIGURE 4: Acute changes in relative preference for food categories measured before and after a single bout of exercise in Responders ( ) and Nonresponders ( ). HF: high fat, LF: low fat, NS: non-sweet, SW: sweet.

TABLE 2: Participant characteristics and changes after medium-term exercise intervention for responders and Nonresponders.

	Wk	Responder	Non-responder	<i>P</i>
Gender (male : female)	—	6 : 14	7 : 7	.25
Age (years)	—	41.4 (8.8)	36.5 (12.3)	.19
Weight (kg)	0	91.5 (11.8)	87.4 (10.1)	.30
	12	85.9 (11.6)	86.5 (10.6)	.88
BMI (kg/m <sup>2</sup> )	0	32.3 (4.3)	29.7 (2.2)	.06
	12	30.9 (4.25)	29.3 (2.5)	.23
VO <sub>2max</sub> (mL/kg/min)	0	30.3 (4.1)	29.4 (2.6)	.52
	12	37.5 (8.7)	35.9 (2.7)	.63
Fat mass (kg)	0	32.9 (9.7)	27.4 (5.3)	.06
	12	27.6 (5.3)	26.0 (6.3)	.60
Lean mass (kg)	0	58.5 (9.3)	60.2 (10.2)	.63
	12	58.4 (9.8)	60.7 (11.0)	.54
Duration of exercise bout (min)	0	58.2 (2.5)	62.7 (2.9)	.25
	12	53.2 (3.4)	56.5 (4.0)	.53
Measured energy expenditure from exercise bout (kcal)	0	527.0 (29.6)	531.0 (44.9)	.89
	12	619.1 (33.0)	616.6 (50.1)	.94
ΔFat mass (kg)	—	-5.3 (2.4)	-1.4 (1.6)	<.0001
ΔLean mass (kg)	—	-0.2 (2.6)	0.5 (1.8)	.45

an increase in wanting for high-fat non-sweet foods was nonsignificant after Bonferroni corrections were applied.

**3.5. Food Preference.** A significant interaction between Responder group and food category on relative preference was revealed [ $F(3,93) = 6.1, P < .0001$ ]. Post hoc tests

confirmed that NR showed an increased preference for high-fat sweet food ( $P < .05$ ). Interestingly, these differences were less pronounced at week 12 compared to week 0. There was no main effect of responder group on food preference [ $F(1,31) = 1.6, P = .2$ ].

## 4. Discussion

The aim of this study was to examine the acute effect of exercise on the reward value of food before and after medium-term regular exercise in overweight and obese volunteers. In accordance with previous research [23, 33, 34], there was a large individual variability in net energy balance, indicating some degree of compensation for the 12-week exercise-induced energy expenditure in 14 out of 34 participants. This variability were specifically associated with differences in fat mass. We hypothesised that acute exercise would increase the reward value of food measured at the outset of the intervention, and that after 12 weeks of regular supervised exercise these effects would be dependent on the degree of energy compensation identified by classifying participants as Responders or Nonresponders based on changes in body composition. We found that rather than differences in food reward emerging at week 12, liking and wanting only increased at baseline in the Nonresponders, while the Responders did not change. Furthermore, this pattern of behaviour in both groups was stable over time. These data provide evidence that compensation associated with lower fat loss is associated with the acute effects of exercise on components of food reward involved in appetite regulation and food choice.

Previous research on exercise and the reward value of food has been limited to cross-sectional studies in lean individuals or trained athletes on taste palatability. One study in overweight sedentary participants provides a notable

TABLE 3: Acute changes in hedonic evaluation of food measured before and after a single bout of exercise at week 0 and week 12 of a supervised daily exercise intervention.

Variable	Wk	Responder				Non-Responder			
		HFNS	LFNS	HFSW	LFSW	HFNS	LFNS	HFSW	LFSW
$\Delta$ Liking	0	-1.2 (4.5)	1.9 (3.4)	-9.7 (4.7)	-3.3 (4.4)	4.5 (5.4)	3.2 (4.1)	9.7 (5.7)	4.1 (5.4)
	12	-1.9 (2.4)	0.9 (2.3)	-2.2 (2.6)	-0.1 (1.7)	12.0 (2.9)	10.6 (2.7)	11.7 (3.2)	10.4 (2.1)
$\Delta$ Wanting	0	1.2 (5.2)	6.7 (3.6)	-5.4 (3.8)	-1.5 (4.1)	8.6 (6.3)	0.1 (4.4)	15.5 (4.6)	7.7 (4.9)
	12	-2.0 (2.2)	2.8 (1.9)	1.4 (2.5)	3.1 (1.9)	10.2 (2.7)	3.7 (2.3)	11.4 (3.0)	4.4 (2.3)
$\Delta$ Preference	0	-0.8 (1.6)	4.4 (1.6)	-5.2 (2.5)	1.4 (2.3)	-0.8 (2.0)	-1.5 (1.9)	6.3 (3.0)	1.4 (2.8)
	12	-1.6 (0.7)	3.2 (1.1)	-3.2 (1.1)	1.6 (1.0)	-0.1 (2.0)	-0.5 (1.3)	0.4 (0.9)	0.2 (1.3)

exception [18]. In a recent review, Elder and Roberts [6] identified 9 studies investigating the acute effect of exercise on palatability [8, 10, 35–41]. The findings from these studies are not consistent but are generally suggestive of an increase in the perceived pleasantness of foods with a range of sensory and macronutrient profiles. None of the studies found a devaluing effect of exercise on food reward. However, Elder and Roberts concluded that “insufficient data are available on whether changes in food preferences and taste perception influence energy balance through macronutrient selection” (page 1). In the present study, we found that those who did not respond to the exercise intervention as predicted were characterised by differences in the reward value of food after an acute bout of exercise. In addition to increases in expected liking for all food categories independent of taste or fat content, explicit wanting and relative preference for high fat sweet foods were accentuated. These findings are consistent with our previous research on exercise-induced compensatory eating in lean women. Individuals who increased their food intake immediately after 50 minutes of moderate intensity exercise responded faster to images of food, reported greater liking for the food, and had an increased preference toward high-fat sweet food [20].

What mechanisms could account for the differences observed in the reward value of food? One hypothesis can be generated by research proposing that short bouts of exercise may stimulate dopamine release in the nucleus accumbens and striatum [17] or in the ventral tegmental area in response to CRF and cortisol [42]. In rats, it was shown that an acute bout of exercise can exert an enhancing effect on reward (similar to a low dose of an addictive drug) via a sensitizing action [17]. Such neural sensitization is thought to involve changes in levels of delta FosB and dopamine transmission in the mesolimbic pathway [43, 44]. It is possible therefore that some individuals experience a form of sensitization to food (and visual food cues) induced by exercise. This could be due to repeated associations between exercise and food seeking behavior that have developed into habit.

Exercise-induced changes in food reward could be an important consideration in the efficacy of exercise as a means to reduce overweight. In particular, an enhanced motivational drive or wanting for food after exercise may help to explain why some people overcompensate during acute eating episodes [20]. The findings of the present study suggest that some individuals have a predisposition to com-

pensate for exercise-induced energy expenditure as a result of changes in food reward. However, they also demonstrate that exercise does not increase the reward value of food in all individuals and may differ according to the characteristics (e.g., macronutrient and sensory profiles) of the food being assessed. This could explain certain discrepancies in the literature on exercise and food palatability [6].

The effects of exercise on food preference can be linked to both the metabolic and cognitive consequences of engaging in physical activity. Furthermore, these domains interact and their impact on appetite regulation will depend on individual predispositions and susceptibility [45]. Future research should aim to identify the characteristics of those individuals who are most likely to respond to regular exercise (see, e.g., [46, 47]). Contrary to our expectations, the differences in liking and wanting immediately after exercise observed between Responders and Nonresponders were present at baseline and remained after 12 weeks of regular supervised exercise. This suggests that hedonic response after exercise may be an enduring predisposition and one that could moderate the effect of exercise on fat loss. In contrast, we observed at week 0 that Nonresponders showed a strong preference for high-fat sweet foods after exercise, but at week 12 the exercise bout had no such effect. With caution, we propose that regular moderate intensity exercise may have a role in correcting the initial preference for high palatability, high-energy food brought about by acute exercise. This interpretation is supported by other 12-week exercise interventions that demonstrate a correcting effect of exercise training on satiety [5] and energy compensation [48].

Some limitations should be noted in the present study. The restricted sample size limited the opportunity to control for numerous background variables or test more complex hypotheses involving combinations of factors. Although water was provided during exercise, we did not measure total consumption; and similarly we did not measure sensations of appetite during the exercise session. Therefore, it was not possible to test whether our results were mediated by hunger, thirst, or differences in water intake. The study design did not include a no-exercise control arm. Although each subject served as their own control before and after the exercise session and before and after the 12-week intervention, we cannot reject the possibility that reward value of food may increase in Nonresponders after the first

set of measures regardless of performing exercise. There is evidence to suggest that prior exposure to the sight and smell of food can increase motivation to eat in the short term [49]. Nevertheless, we argue that 500 kcal of moderate intensity exercise is more likely having a greater modulating effect on food reward in Nonresponders than mere exposure to food cues. Moreover, we only assessed the reward value of food once before and after exercise at week 0 and week 12. Although the immediate and one-week test-retest reliability of the LFPQ is acceptable, further verification of the effects we observed would strengthen our interpretation. Another issue is the use of visual food stimuli to assess hedonic evaluation of food. It is unknown whether we would have demonstrated similar effects if we measured liking or wanting and preference for food using more potent sensory cues such as smell, taste, or ingestion. It is possible that Nonresponders would be more able to inhibit their spontaneous responses to food images compared to smelling or tasting the food presented. Similarly, the exercise-induced reduction in liking and wanting for high-fat sweet food in the responders might be accentuated due to greater aversion to stronger sensory cues.

## 5. Conclusion

To conclude, overweight and obese individuals who showed an immediate postexercise increase in expected liking for food and more specifically an increased wanting and preference for high-fat sweet foods displayed a smaller reduction in fat mass with exercise. Increased liking for foods can promote higher compensation of energy intake in response to exercise. This enhanced liking was not attenuated by prolonged exercise (or change in body composition) suggesting that it is a strong habitual trait. This maintenance of a strong positive rating of liking for foods can, apparently, offset subtle changes in preferences among food groups which tend towards a more healthy eating style. For some individuals, exercise increases the reward value of high palatability, high energy food and diminishes the impact of exercise on fat loss. Early identification of this predisposition could help to optimise weight control strategies by augmenting the health benefits of exercise with dietary modification or pharmacotherapy.

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## Clinical Study

# Influence of Physical Activity Participation on the Associations between Eating Behaviour Traits and Body Mass Index in Healthy Postmenopausal Women

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Available data reveals inconsistent relationships between eating behaviour traits and markers of adiposity level. It is thus relevant to investigate whether other factors also need to be considered when interpreting the relationship between eating behaviour traits and adiposity. The objective of this cross-sectional study was thus to examine whether the associations between variables of the Three-Factor Eating Questionnaire (TFEQ) and adiposity are influenced by the level of physical activity participation. Information from the TFEQ and physical activity was obtained from 113 postmenopausal women ( $56.7 \pm 4.2$  years;  $28.5 \pm 5.9$  kg/m<sup>2</sup>). BMI was compared between four groups formed on the basis of the physical activity participation and eating behaviour traits medians. In groups of women with higher physical activity participation, BMI was significantly lower in women who presented higher dietary restraint when compared to women who had lower dietary restraint ( $25.5 \pm 0.5$  versus  $30.3 \pm 1.7$  kg/m<sup>2</sup>,  $P < .05$ ). In addition, among women with lower physical activity participation, BMI was significantly lower in women presenting a lower external hunger than in those with a higher external hunger ( $27.5 \pm 0.8$  versus  $32.4 \pm 1.1$  kg/m<sup>2</sup>,  $P < .001$ ). Our results suggest that physical activity participation should also be taken into account when interpreting the relationship between adiposity and eating behaviour traits.

## 1. Introduction

The regulation of energy intake in humans is based on a series of complex mechanisms that is not solely driven by homeostatic factors such as hunger and satiety signals [1]. It has been suggested that cognitions and emotions are largely involved in the regulation of energy intake [2]. Different tools have been proposed to grasp the complexity of eating behaviour traits in humans. Among them, the Three-Factor Eating Questionnaire developed by Stunkard and Messick assesses three dimensions of eating behaviour traits: dietary restraint, disinhibition, and hunger [3]. Briefly, dietary restraint is defined as a conscious control of food

intake with concerns about shape and weight, disinhibition refers to an overconsumption in response to a variety of stimuli associated with a loss of control on food intake, and hunger is the food intake in response to feelings and perception of hunger [4]. This questionnaire has been widely used to study the association between eating behaviour traits and body weight [3].

The association between dietary restraint and (BMI) is uncertain; some authors have found no association [5–8] while others have found that the two were inversely related [9–11]. Generally, weight-loss intervention studies have demonstrated that subjects who achieved larger weight losses when dieting are also those in whom the greatest

increase in dietary restraint is noted [6, 9, 10, 12, 13]. In addition, the success of weight-loss interventions has also been associated to lower pre-weight-loss dietary restraint [10, 14]. Similarly, results from a longitudinal study have shown that a lower dietary restraint at baseline was associated with lower weight gain during a 6-year follow-up period [15]. Therefore in the long term, it is not clear whether it is preferable to have higher or lower dietary restraint for optimal body weight management. On the other hand, the association between disinhibition and BMI is more consistent as many studies have shown that higher dietary disinhibition is associated with higher BMI and a higher likelihood of weight gain over time [5, 7, 16–18]. Similarly, a positive correlation between hunger and BMI has been reported [5, 17].

It has also been demonstrated that physical activity, apart from its impact on energy expenditure, could also influence energy intake. In fact, studies have suggested that physically active individuals are more likely to eat a healthy diet than sedentary individuals are. Physically active individuals consume more fruits and vegetables and have higher intakes of fiber and calcium than sedentary individuals do [19, 20], which have been shown to favourably influence appetite and energy intake [21, 22]. As well, physical activity can influence eating behaviour by improving satiety, by altering macronutrient preference, and by modulating the hedonic response to foods [23–26].

Considering the above-mentioned evidence suggesting that BMI is influenced by eating behaviour traits and that physical activity is generally associated with healthier food habits, the main objective of this paper was to investigate whether physical activity participation could influence the associations between eating behaviour traits and BMI in postmenopausal women. Since it has been reported that exercise exerts some effects on eating patterns and that it has been shown to be more effective to regulate energy intake in restrained compared to nonrestrained eaters [27], we hypothesized that a negative association between dietary restraint and BMI would only be observed in women with higher physical activity participation. In addition, based on the fact that exercise does not act as a disinhibitor but rather increases the preference for low-fat foods and reduces the motivation to eat [28, 29], we also hypothesized that the positive associations between disinhibition and hunger with BMI would be attenuated with increased physical activity participation.

## 2. Experimental Methods

**2.1. Participants.** The main objective of this cross-sectional study, conducted between 2000 and 2003, was to determine the relative contribution of visceral adipose tissue and insulin resistance to the cardiovascular risk profile of postmenopausal women [30]. A total of 386 women responded to the local newspapers of the Québec City metropolitan area [31]. As described by Major et al., one hundred ninety women were found to be eligible [31]. Among them, 69 dropped out of the study for personal reasons after having

received a complete description of the research protocol [31]. Eight women who have either not totally completed the physical activity questionnaire or have answered less than 80% of each factor (restraint, disinhibition and hunger) were not included in the database. Specifically, having answered to at least 17/21, 13/16, and 12/14 items for restraint, disinhibition and hunger were respectively needed to include the data in our analysis. In case of missing data, the scores were then calculated by extrapolation using a rule of three. Therefore, a total of 113 Caucasian women aged between 46 and 67 years were included in the analyses for this paper. Women were individually interviewed to evaluate whether they satisfied study's inclusion criteria for age, postmenopausal status (confirmed by absence of menses for at least 1 year and levels of follicle-stimulating hormone between 28 and 127 IU·L<sup>-1</sup>), absence of any hormone therapy (HT), and other medication, except a stable dose of thyroxine that well-controlled a hypothyroidism's diagnosis. At the time of inclusion, women had a stable weight for at least 2 months ( $\pm 2.5$  kg), were not dieting, had no chronic diseases, and were not taking medication that could impact on the study outcome. Women with cardiovascular disease, dyslipidemia, or endocrine disorders were excluded. This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all the procedures involving human subjects were approved by the Université Laval Medical Ethics Committee. Written informed consent was obtained from all subjects/patients.

**2.2. Anthropometry.** Body weight was measured to the nearest 0.1 kg using a calibrated weighing device including a tension gauge (Intertechnology Inc.) and a Digital Panel Indicator (Beckman industrial series 600). Fat mass was evaluated with the hydrostatic weighing technique, as described elsewhere [32]. Standing height was measured to the nearest millimeter using a wall stadiometer without shoes. Waist circumference was assessed in duplicate at the mid-distance between iliac crest and last rib margin with a flexible steel metric tape to the nearest 0.1 cm.

**2.3. Eating Behaviour Traits.** Eating behaviour traits were evaluated using the Three-Factor Eating Questionnaire, a 51-item validated questionnaire [3, 33]. It assesses 3 factors and specific subscales that refer to cognitions and behaviours which have been reported to show good test–retest reliability [3, 6, 33, 34]. Dietary restraint is a conscious control of food intake to control body weight [3–5]. This factor can be divided into rigid dietary restraint (dichotomous, all-or-nothing approach to eating, dieting, and weight) and flexible dietary restraint (gradual approach to eating, dieting, and weight) [6]. Dietary disinhibition is characterized by an overconsumption of foods in response to a variety of stimuli (e.g., emotional stress) associated with a loss of control on food intake [3–5]. It is further divided into three specific subscales: habitual susceptibility to disinhibition (behaviours that may occur when circumstances predispose to recurrent disinhibition), emotional susceptibility to disinhibition (disinhibition associated with negative affective states), and

situational susceptibility to disinhibition (disinhibition initiated by specific environmental cues) [34]. Hunger represents food intake in response to feelings and perceptions of hunger. Internal hunger (hunger interpreted and regulated internally) and external hunger (triggered by external cues) are the two specific subscales that can be derived from the hunger factor [4, 34].

**2.4. Physical Activity Participation.** Physical activity participation was defined using the 3-day activity diary record by Bouchard et al. [35] that was administered during two weekdays and one weekend day. Each day (24 hours) is divided into 96 periods, 15-minutes each. As previously described by Major et al., [31] women reported the dominant activity that they were engaged in for each 15-minute period and indicated the corresponding number (from 1 to 9). If their specific activities were not included into the list, they were instructed to choose an activity with similar intensity. As an example, category 1 refers to activities of very low energy expenditure (e.g., sleeping and resting in bed), category 6 refers to leisure activities and sports in a recreational environment (e.g., golf, baseball, and volleyball), and category 9 refers to activities of very high energy expenditure (e.g., running) [35]. Our study focused on mean daily energy expenditure from activities in categories 6, 7, 8, and 9 (EE6–9), which have an energy cost  $>1.2 \text{ kcal} \cdot \text{kg}^{-1} \cdot 15 \text{ min}^{-1}$  ( $>4.8 \text{ METs}$ ) (i.e., 1.2, 1.4, 1.5, and  $2 \text{ kcal} \cdot \text{kg}^{-1} \cdot 15 \text{ min}^{-1}$  for categories 6, 7, 8, and 9, resp.). As previously described by Major et al., [31] EE6–9 was calculated by multiplying the number of 15-minute periods of categories 6 to 9 by the approximate median energy cost of each category. As such, the following formula was used:  $\text{EE6-9} = (\text{number of 15-minute periods of category 6} \times 1.2) + (\text{number of 15-minute periods of category 7} \times 1.4) + (\text{number of 15-minute periods of category 8} \times 1.5) + (\text{number of 15-minute periods of category 9} \times 2)$ . The result was then used to calculate the mean EE6–9 value for 3 days ( $\text{kcal} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$ ) and was used for further analyses [35]. The main limitation of this physical activity diary relates to the approximation of the energy cost since each categorical value is the approximate median amount of energy expended when engaged in the activities of the specific category [35]. The 3-day activity diary record has nonetheless been validated [35], and results suggest that it represents an appropriate way to estimate mean daily energy expenditure and frequency of participation in activities from different categories. In addition, it has been suggested, in a study conducted in the same cohort, that women with higher physical activity participation had a better metabolic profile (insulin sensitivity and lipid levels) for a given level of visceral adipose tissue, which is concordant with the well-known beneficial effects of a higher physical activity participation on metabolic profile [31].

**2.5. Food Record.** Dietary intakes were collected using a 3-day weighed food record, which was completed during two weekdays and one weekend day (same days as the 3-day activity diary). Guidelines for completing the food record were explained to participants by the study's registered

dietitian. Women were asked to weigh foods with a scale provided by the research team. The evaluation of nutrient intakes derived from the food record was performed using the Nutrition Data System for Research software (version 4.03, developed by the Nutrition Coordination Center, University of Minnesota, Minneapolis, MN, Food and Nutrient Database 31, released in November 2000) [36]. All records were reviewed by the study's registered dietitian upon collection. In order to control for underreporting in our study population, subjects who reported an energy intake of less than 1 standard deviation from the mean reported energy intake were excluded from the dietary analysis (22 and 14 subjects in the lower and higher physical activity participation group, resp.). Thus, the number of subjects included in the dietary analysis (42 and 35 subjects in the lower and higher physical activity participation group, resp.) is different from the numbers included for the main outcome of the study (64 and 49 subjects in the lower and higher physical activity participation group, resp.).

**2.6. Statistical Analyses.** Statistical analyses were performed with the use of SPSS software (version 11.5; SPSS Inc, Chicago, IL). The median value of EE6–9 ( $2 \text{ kcal} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$ ) was used to form two groups: women with lower and higher physical activity participation. Difference between the two groups for anthropometric variables, eating behaviour traits, and dietary intakes were assessed using Student *t*-tests. Pearson correlations were used to examine associations between BMI and eating behaviour traits within women characterized by lower and higher physical activity participation. Comparisons of the correlation coefficient strength between groups were performed using MedCalc software [37]. BMI was compared between the four groups formed on the basis of the physical activity participation median and of the dietary restraint median ( $2 \text{ kcal} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$  and a score of 9, resp.), by using an analysis of variance (ANOVA), followed by Tukey *post hoc* tests. The same analyses were performed with groups formed on the basis of the physical activity participation median and external hunger median ( $2 \text{ kcal} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$  and a score of 2, resp.). A general linear model was also performed to compare the interactions between variables. Eating behaviour traits that were significantly correlated with BMI were used in multivariate linear regressions analyses (i.e., enter) with BMI as a dependent variable. In addition, when a given TFEQ factor and some of its subscales were significantly related to BMI, we chose to enter the subscales rather than the main factor in the multivariate model in order to avoid problems related to multicollinearity. Values are presented as means  $\pm$  standard deviation. Differences with *P*-values  $<.05$  were considered statistically significant.

### 3. Results

Participant characteristics' from the 2 groups formed on the basis of physical activity participation (according to the EE6–9 median value of  $2 \text{ kcal} \cdot \text{kg}^{-1} \cdot \text{day}^{-1}$ ) are shown in Table 1. Participants with lower physical activity participation had

TABLE 1: Anthropometric variables, eating behaviour traits, and dietary intakes in women characterized by either lower or higher physical activity participation.

<i>n</i>	Lower physical activity participation		Higher physical activity participation		<i>P</i> -value
	Mean	SD	Mean	SD	
	64		49		
Age (y)	57.1	4.5	56.2	3.9	.30
EE6-9 (kcal·kg <sup>-1</sup> ·day <sup>-1</sup> )	0.5	0.7	6.6	3.9	<.0005
Anthropometric variables					
Body weight (kg)	74.1	14.7	71.3	17.7	.37
BMI (kg/m <sup>2</sup> )	29.1	5.7	27.8	6.3	.23
Fat mass (%) <sup>1</sup>	40.2	7.7	37.4	7.1	.05
Waist circumference (cm) <sup>2</sup>	93.0	13.7	88.4	12.7	.07
Eating behaviour traits					
Dietary restraint	9.0	4.6	9.7	4.3	.44
Flexible dietary restraint	3.2	1.8	3.3	1.9	.84
Rigid dietary restraint	2.6	1.6	2.6	1.7	.98
Disinhibition	6.4	3.6	6.0	3.9	.55
Habitual disinhibition	1.3	1.5	1.1	1.4	.45
Emotional disinhibition	1.3	1.2	1.4	1.3	.77
Situational disinhibition	2.2	1.7	1.9	1.6	.28
Hunger	4.6	3.6	4.6	3.8	.98
Internal hunger	1.8	2.0	1.5	1.8	.41
External hunger	2.0	1.6	2.1	1.8	.93
	42		35		
Dietary intakes					
Energy (kcal)	1981.4	275.6	1870.8	190.5	.05
Dietary fat (% of energy) <sup>3</sup>	32.8	4.9	31.3	4.5	.17
Carbohydrate (% of energy) <sup>3</sup>	48.8	5.3	49.7	5.0	.44
Protein (% of energy) <sup>3</sup>	16.4	2.7	16.8	2.2	.50
Cholesterol (mg)	274.8	119.5	227.8	85.9	.06
Fiber (g·1000 kcal <sup>-1</sup> )	11.3	3.4	12.5	2.6	.09

Values are means ± SD. Groups were formed according to the EE6-9 median value (2 kcal·kg·day<sup>-1</sup>).

<sup>1</sup>for fat mass, *n* = 61 in lower physical activity participation, and *n* = 47 in higher physical activity participation;

<sup>2</sup>for waist circumference, *n* = 48 in higher physical activity participation;

<sup>3</sup>for dietary fat, carbohydrate and protein, *n* = 41 in lower physical activity participation.

significantly higher percentage of body fat ( $40.2 \pm 7.7$  versus  $37.4 \pm 7.1\%$ ,  $P < .05$ ) and tended to have greater waist circumference ( $93.0 \pm 13.7$  versus  $88.4 \pm 12.7$  cm,  $P = .07$ ). No significant differences in eating behaviour traits were noted between groups divided based on physical activity participation. With regards to dietary intakes, it was found, after removing underreporters from the sample, that women with lower physical activity participation consumed significantly more energy when compared to women with higher physical activity participation ( $1981.4 \pm 275.6$  versus  $1870.8 \pm 190.5$  kcal,  $P < .05$ ). No significant group differences were noted for macronutrient intakes. Trends were also found for dietary cholesterol and fiber consumption and suggested a higher cholesterol ( $274.8 \pm 119.5$  versus  $227.8 \pm 85.9$  mg,  $P = .06$ ) and a lower fiber consumption ( $11.3 \pm 3.4$  versus  $12.5 \pm 2.6$  g·1000 kcal<sup>-1</sup>,  $P = .09$ ) in women with lower physical activity participation when compared to women with higher physical activity participation.

Significant correlations were observed between eating behaviour traits and BMI in both groups of women separated on the basis of physical activity participation (Table 2). In women with lower physical activity participation, flexible dietary restraint was negatively associated with BMI ( $r = -0.24$ ,  $P < .05$ ) while disinhibition ( $r = 0.55$ ,  $P < .0001$ ) and its subscales (habitual ( $r = 0.49$ ,  $P < .0001$ ), emotional ( $r = 0.58$ ,  $P < .0001$ ), and situational ( $r = 0.35$ ,  $P < .005$ )) as well as hunger ( $r = 0.45$ ,  $P < .0001$ ) and its subscales (internal ( $r = 0.41$ ,  $P < .001$ ) and external hunger ( $r = 0.49$ ,  $P < .0001$ )) were all positively associated with BMI. In the group with higher physical activity participation, dietary restraint ( $r = -0.54$ ,  $P < .0001$ ) and its subscales (flexible ( $r = -0.55$ ,  $P < .0001$ ) and rigid ( $r = -0.37$ ,  $P < .01$ ) dietary restraint) were negatively associated with BMI. In contrast, disinhibition ( $r = 0.42$ ,  $P < .005$ ), emotional ( $r = 0.41$ ,  $P < .005$ ) and situational susceptibility to disinhibition ( $r = 0.30$ ,  $P < .05$ ) as well as susceptibility to hunger ( $r = 0.33$ ,  $P < .05$ )

TABLE 2: Pearson's correlation coefficients for the associations between eating behaviour traits, and BMI in women characterized by either lower or higher physical activity participation.

Eating behaviour traits	Pearson correlations with BMI		Comparison of correlation strength
	Lower physical activity participation	Higher physical activity participation	<i>P</i> -values
<i>n</i>	64	49	
Dietary restraint	-0.16 <sup>NS</sup>	-0.54 <sup>***</sup>	.02
Flexible dietary restraint	-0.24 <sup>*</sup>	-0.55 <sup>***</sup>	.06
Rigid dietary restraint	-0.04 <sup>NS</sup>	-0.37 <sup>ζ</sup>	.07
Disinhibition	0.55 <sup>***</sup>	0.42 <sup>**</sup>	.38
Habitual disinhibition	0.49 <sup>***</sup>	0.24 <sup>NS</sup>	.14
Emotional disinhibition	0.58 <sup>***</sup>	0.41 <sup>**</sup>	.25
Situational disinhibition	0.35 <sup>**</sup>	0.30 <sup>*</sup>	.77
Hunger	0.45 <sup>***</sup>	0.33 <sup>*</sup>	.47
Internal hunger	0.41 <sup>§</sup>	0.20 <sup>NS</sup>	.23
External hunger	0.49 <sup>***</sup>	0.14 <sup>NS</sup>	.04

<sup>\*</sup>, *P* < .05; <sup>ζ</sup>, *P* < .01; <sup>\*\*</sup>, *P* < .005; <sup>§</sup>, *P* < .001; <sup>\*\*\*</sup>, *P* < .0001; <sup>NS</sup>, not significant.

were all positively associated with BMI. Similar results were obtained when percent body fat was correlated with eating behaviour traits (results not shown).

Because correlations obtained with percentage of body fat were similar to those with BMI and that BMI represents an easily accessible proxy of adiposity, further analyses were conducted with BMI. Comparisons of correlation coefficients for the associations between eating behaviour traits and BMI were performed between women with lower and higher physical activity participation. Results showed significant differences in correlation coefficient for dietary restraint (*P* = .02) and for external hunger (*P* = .04). For dietary restraint, a stronger correlation with BMI was found in women in the higher physical activity participation compared to those in the lower physical activity participation group (*r* = -0.54 versus *r* = -0.16, *P* = .02). For external hunger, a stronger correlation was found in women from the lower physical activity participation group than in those from the higher physical activity participation group (*r* = 0.49 versus *r* = 0.14, *P* = .04). Trends were also found for flexible and rigid dietary restraint (*P* < .06 and *P* < .07, resp.) whereas stronger correlations observed with BMI were found in the higher physical activity participation group. As such, analyses were performed with eating behaviour traits for which a significant difference in the strength of correlation with BMI was observed between women in the lower and higher physical activity participation groups

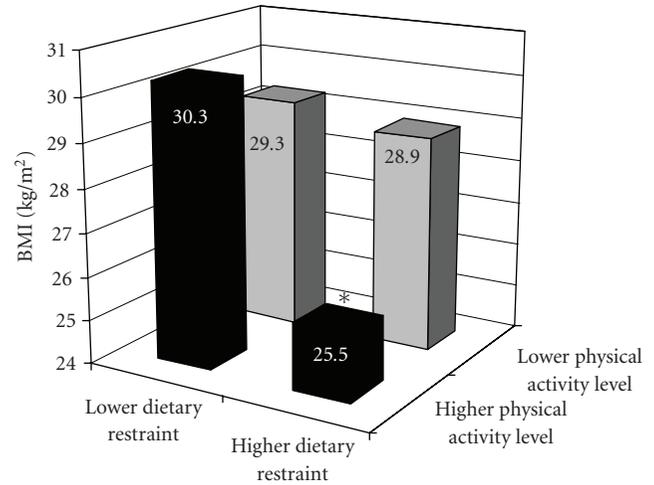


FIGURE 1: Body mass index in the group of postmenopausal women is separated on the basis of dietary restraint and physical activity participation. Lower and higher physical activity participation are presented in grey and in black respectively. \* indicates a significant difference in women with lower dietary restraint and higher physical activity participation. For lower physical activity participation and lower dietary restraint, *n* = 37, and mean BMI = 29.3 ± 1.0 kg/m<sup>2</sup>; for lower physical activity participation and higher dietary restraint *n* = 27, and mean BMI = 28.9 ± 0.9 kg/m<sup>2</sup>; for a higher physical activity participation and lower dietary restraint, *n* = 23, and mean BMI = 30.3 ± 1.7 kg/m<sup>2</sup> and for a higher physical activity participation and higher dietary restraint, *n* = 26, and mean BMI = 25.5 ± 0.5 kg/m<sup>2</sup>.

(i.e., dietary restraint and external hunger). Figure 1 shows the difference in the association between dietary restraint and BMI according to physical activity participation. Among women with lower physical activity participation, BMI was not different between women with either lower (mean: 29.3 ± 1.0 kg/m<sup>2</sup>) or higher dietary restraint (mean: 28.9 ± 0.9 kg/m<sup>2</sup>). On the other hand, among women with higher physical activity participation, BMI was significantly higher in women with lower dietary restraint (mean: 30.3 ± 1.7 kg/m<sup>2</sup>) when compared to women with higher dietary restraint (mean: 25.5 ± 0.5 kg/m<sup>2</sup>). Finally, it was also found that physical activity participation had an impact on the association between external hunger and BMI (Figure 2). Among women with lower physical activity participation, BMI was significantly lower in women with lower external hunger (mean: 27.5 ± 0.8 kg/m<sup>2</sup>) than in those with higher external hunger (mean: 32.4 ± 1.1 kg/m<sup>2</sup>). No such differences were observed in women with higher physical activity participation (mean: 27.2 ± 1.3 and 28.6 ± 1.1 kg/m<sup>2</sup> for groups with lower and higher external hunger group, resp.).

In order to investigate the relative and independent contribution of eating behaviour traits to the variability of BMI in both the lower and higher physical activity participation groups, multiple regression analysis (i.e., enter) was performed. Eating behaviour traits were included in the regression analyses if they were significant correlates of BMI. When both the subscales and the main TFEQ

TABLE 3: Independent predictors of BMI in women with lower physical activity participation ( $n = 64$ ).

Variables	Beta	P-value
Emotional disinhibition	0.387	.004
External hunger	0.259	.103

$r^2 = 0.411$  (adjusted = 0.349),  $F = 6.618$ ,  $P < .0001$ .

Note: Variables included in the model were those which were significantly correlated with BMI (flexible dietary restraint, habitual disinhibition, emotional disinhibition, situational disinhibition, internal hunger, and external hunger). In addition, when a given TFEQ factor and some of its subscales were significantly related to BMI, we chose to enter the subscales rather than the main factor in the multivariate model in order to avoid problems related to multicollinearity.

TABLE 4: Independent predictors of BMI in women with higher physical activity participation ( $n = 49$ ).

Variables	Beta	P-value
Flexible dietary restraint	-0.343	.016
Rigid dietary restraint	-0.300	.017
Emotional disinhibition	0.317	.057

$r^2 = 0.443$  (adjusted = 0.378),  $F = 6.845$ ,  $P < .0001$ .

Note: Variables included in the model were those which were significantly correlated with BMI (flexible dietary restraint, rigid dietary restraint, emotional disinhibition, situational disinhibition, and hunger). In addition, when a given TFEQ factor and some of its subscales were significantly related to BMI, we chose to enter the subscales rather than the main factor in the multivariate model in order to avoid problems related to multicollinearity.

factor were significant correlates, only the subscales were entered into the model. As such, emotional disinhibition and to a lesser amount external hunger were found to be independent contributors to BMI (35% of the variance after adjustment) in women with lower physical activity participation (Table 3) while flexible dietary restraint, rigid dietary restraint, and to a lesser amount emotional disinhibition were the independent contributors to BMI (38% of the variance after adjustment) in women with higher physical activity participation (Table 4).

#### 4. Discussion

The main objective of this paper was to investigate whether physical activity participation could interrelate with the associations between eating behaviour traits and BMI. Our results suggest, for the first time, that dietary restraint is more strongly correlated with BMI in women with higher physical activity participation than in women with lower physical activity participation. Moreover, flexible dietary restraint and rigid dietary restraint are independent predictors of BMI only in women with higher physical activity participation. Our analyses also revealed that emotional disinhibition contributes to the variance in BMI in women with lower physical activity participation and only marginally in women with higher physical activity participation. Finally, hunger, and more particularly external hunger, is strongly correlated with BMI in women with lower physical activity participation.

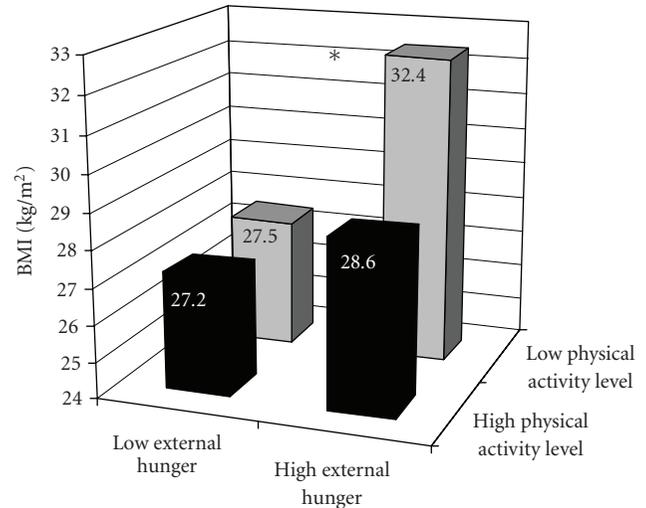


FIGURE 2: Body mass index in the group of postmenopausal women is separated on the basis of external hunger and physical activity participation. Lower and higher physical activity participation are presented in grey and in black respectively. \* indicates a significant difference in women with lower external hunger and lower physical activity participation. For lower physical activity participation and lower external hunger,  $n = 43$ , and mean BMI =  $27.5 \pm 0.8$  kg/m<sup>2</sup>; for lower physical activity participation and higher external hunger,  $n = 21$ , and mean BMI =  $32.4 \pm 1.1$  kg/m<sup>2</sup>; for higher physical activity participation and lower external hunger,  $n = 31$ , and mean BMI =  $27.2 \pm 1.3$  kg/m<sup>2</sup> for a higher physical activity participation and higher external hunger,  $n = 18$ , and mean =  $28.6 \pm 1.1$  kg/m<sup>2</sup>.

It is well documented that both physical activity and dietary restraint impact body weight management. However, the influence of physical activity on the association between dietary restraint and weight has not been well established. Our results show that postmenopausal women with higher physical activity participation and higher dietary restraint have a lower BMI when compared to women with higher physical activity participation and lower dietary restraint. This suggests that physical activity participation influences the relationship between dietary restraint and BMI. This may be partially explained by the observation that women with higher physical activity participation seem to present healthier food habits (lower cholesterol intakes and higher fiber intake) when compared to women with lower physical activity participation, and this, despite similar dietary restraint. These findings are concordant with other studies showing that women with higher physical activity participation are more likely to consume a healthy diet and to be characterized by healthier eating patterns [19, 20, 23–25]. The observation that women who exercise seem to have the capacity to better regulate their appetite and that exercise can also possibly raise the perceived pleasantness of low-fat foods may partly explain why active women are more likely to choose a healthier diet, including foods with a low fat content [23, 25, 38].

Another explanation to how physical activity participation could influence the association between dietary restraint and BMI relates to the association between dietary restraint

and disinhibition. In fact, some studies have underlined the heterogeneity of the association between dietary restraint and disinhibition, with results reporting negative [5, 39, 40], positive [39, 40], or no association [5, 41, 42] between these variables. Our results have shown an association between dietary restraint and disinhibition in women with higher physical activity participation while no significant correlation between these variables was found for women with lower physical activity participation ( $r = -0.29$ ,  $P < .05$ ;  $r = -0.16$ ,  $P = \text{NS}$ ; higher and lower physical activity participation, resp.). This observation is also strengthened by the fact that disinhibition, in the higher physical activity participation group, was significantly lower in women who displayed a higher dietary restraint when compared to women with a lower dietary restraint ( $4.9 \pm 3.1$  versus  $7.2 \pm 4.4$ ,  $P = .04$ , resp.). No such significant differences in disinhibition were noted when women with either lower or higher dietary restraints were compared with women in the lower physical activity participation groups. Since a lower disinhibition level has been reported in many studies to be predictive of a lower BMI [5, 7, 16–18], the inverse association between dietary restraint and disinhibition among women with a higher physical activity participation could explain, at least in part, the fact that a higher dietary restraint is associated to a lower BMI among this group of women.

Our results also showed that although flexible dietary restraint and rigid dietary restraint were both significant predictors of BMI, flexible dietary restraint was the strongest predictor, explaining 34% of the variance in BMI among women with higher physical activity participation. These results are concordant with previous studies showing that flexible dietary restraint is a better predictor of lower BMI than rigid dietary restraint [5]. For example, longitudinal studies showed that changes in flexible dietary restraint, but not changes in rigid dietary restraint, correlated negatively with changes in body weight [8, 15].

It has been previously shown that a higher disinhibition level predicts higher BMI and higher likelihood of weight gain [5, 7, 16–18]. Our results add to this literature by showing that in women with higher physical activity participation, disinhibition does not predict the variability in BMI ( $P = .06$ ) while it predicted 39% of BMI variability among women with lower physical activity participation ( $P < .005$ ). Therefore, in women with higher physical activity participation, disinhibition does not seem to have as much of an impact on BMI when dietary restraint is taken into account. In fact, it can be hypothesized that after a disinhibition episode, women with a higher physical activity participation are able to respond by reducing their energy intake over the course of the following meals in order to minimize the impact of disinhibition on energy balance and/or increase their physical activity.

Among women with lower physical activity participation, a higher BMI was noted in women characterized by higher external hunger when compared to those with lower external hunger. In contrast, no difference in BMI was observed according to external hunger value among women with higher physical activity participation. Interestingly, we found that among women with lower physical activity

participation, external hunger was positively associated with energy intake ( $r = 0.36$ ;  $P < .005$ ), the percent of energy from dietary lipids ( $r = 0.29$ ;  $P < .05$ ), and cholesterol intake ( $r = 0.32$ ;  $P < .01$ ). No such associations were noted in women with higher physical activity participation. Therefore, women with lower physical activity participation and higher external hunger, increased energy and dietary fat intake could explain, at least in part, their increased BMI. The reasons why external hunger is not associated with dietary factors potentially leading to positive energy balance among women with higher physical activity participation will have to be further elucidated.

Our findings are limited to a small population of postmenopausal women and should thus be interpreted accordingly. In addition, even if it remains that the 3-day activity diary record has been previously validated and that the use of self-reported physical activity and dietary data are, to some extent, a limitation. Furthermore, the cross-sectional nature of this study makes it difficult to underline the possible interactions between behaviour, environment, and genes. Thus, it does not exclude the possibility that other variables might influence interactions between eating behaviour traits and BMI. Because of the cross-sectional nature of this study, it is obvious that we cannot allude to any causality for physical activity participation on the association between eating behaviour traits and BMI. It is nonetheless tempting to speculate that depending on their level of physical activity participation, some individuals could react differently to eating behaviour interventions aimed at preventing weight gain or inducing weight loss. For example, it might be suggested that increasing dietary restraint might be a more efficient approach to lose weight or to avoid weight gain among women with higher physical activity participation than in those with lower physical activity participation. Of course, this remains to be tested in well-designed weight management interventions.

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## Research Article

# The Acute Effects of Swimming on Appetite, Food Intake, and Plasma Acylated Ghrelin

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Swimming may stimulate appetite and food intake but empirical data are lacking. This study examined appetite, food intake, and plasma acylated ghrelin responses to swimming. Fourteen healthy males completed a swimming trial and a control trial in a random order. Sixty min after breakfast participants swam for 60 min and then rested for six hours. Participants rested throughout the control trial. During trials appetite was measured at 30 min intervals and acylated ghrelin was assessed periodically (0, 1, 2, 3, 4, 6, and 7.5 h.  $N = 10$ ). Appetite was suppressed during exercise before increasing in the hours after. Acylated ghrelin was suppressed during exercise. Swimming did not alter energy or macronutrient intake assessed at buffet meals (total trial energy intake: control 9161 kJ, swimming 9749 kJ). These findings suggest that swimming stimulates appetite but indicate that acylated ghrelin and food intake are resistant to change in the hours afterwards.

## 1. Introduction

Regular physical activity is important for the maintenance of body weight and its composition within a healthy range [1, 2]. All forms of physical activity can contribute to successful energy balance by increasing daily energy expenditure. Swimming is an attractive mode of physical activity due to the reduced musculoskeletal and thermoregulatory stresses (i.e., elevation in body temperature) imposed in comparison with other land-based activities such as running and cycling. Swimming may therefore offer an appealing form of physical activity for individuals seeking to prevent weight gain and/or to maintain a reduced body weight after successful weight loss.

Despite the attractiveness of swimming as a mode of physical activity, the ability of swimming to favourably influence body weight and body composition remains contentious. In obese individuals research has shown that swimming may not induce body weight and fat loss [3, 4] whereas walking and cycling interventions of similar intensity and duration do [3]. Considering the heightened energy output elicited by all forms of exertion the most logical explanation for these findings is that swimming stimulates

a compensatory increase in energy intake [5]. This notion is consistent with anecdotal reports of swimming stimulating appetite. Specifically, it has been stated that individuals often feel like “eating a horse” after an acute bout of swimming [6]. This suggestion is consistent with empirical research which has described elevations in energy intake after cycling-based exercise performed on a modified ergometer in cold water [5, 7]. Despite these findings, there remains a paucity of data about the precise effects of swimming on appetite and food intake.

The mechanisms by which exercise influences appetite have recently begun to receive significant interest with specific attention being given to peptides implicated in the neuroendocrine regulation of feeding [8, 9]. Ghrelin is an acylated peptide secreted primarily from the stomach and remains unique as the only circulating gut peptide that stimulates appetite [10]. Defined roles of ghrelin in both short- and long-term feeding regulation have been uncovered [11], and more recently investigators have sought to determine how exercise influences circulating levels of ghrelin [12–14]. These studies suggest that intense exercise induces a transient suppression in circulating acylated ghrelin concentrations. Concomitant suppressions in hunger have been reported by

Broom and colleagues [12, 14] raising the possibility that acylated ghrelin may be important in determining changes in appetite resulting from exercise.

The primary aim of this investigation was to examine the influence of an acute bout of swimming on appetite and energy intake in an effort to determine whether a stimulatory increase in these variables may explain data suggesting a relative inefficacy of swimming for the purposes of weight control. A subsidiary aim of this investigation was to explore the potential role of acylated ghrelin as a mediator of appetite and food intake, during and after exercise.

## 2. Methods

**2.1. Participants.** Following university ethical advisory committee approval 14 healthy male volunteers (age  $22.0 \pm 0.5$  y, BMI  $23.2 \pm 0.6$  kg·m<sup>2</sup>, body fat  $17.2 \pm 1.2\%$ , mean  $\pm$  SEM) gave their written informed consent to participate. Participants were nonsmokers, had no known history of cardiovascular/metabolic disease, were not dieting, did not have any atypical dietary habits (assessed by the three-factor eating questionnaire), were not taking medication, and were not obese (BMI  $\leq 29.9$  kg·m<sup>2</sup>) or hypertensive (resting blood pressure  $< 140/90$  mmHg). Participants were habitually active but were not trained athletes, with most individuals typically participating in games activities such as soccer, hockey, and rugby on a regular basis at a recreational level. The nature of the study demanded that participants were competent at swimming; however, it was ensured that individuals taking part in swimming at a competitive level were not recruited for the study.

**2.2. Procedure.** Prior to main trials participants visited the laboratory to undergo screening and preliminary testing. On arrival at the laboratory participants were provided with an information sheet detailing the demands of the study. The information sheet stated that the aims of the study were to examine the effects of swimming on appetite, energy intake, and acylated ghrelin but did not provide any indication of the hypothesised direction of responses. After confirming that participants understood the study demands written informed consent was obtained. Thereafter, questionnaires were completed to assess health status, physical activity habits, and food preferences. Height was determined to the nearest 0.1 cm using a stadiometer (Seca 214, Seca Ltd, Germany), and body weight was measured to the nearest 0.1 kg using a digital scale (Seca 770, Seca Ltd, Germany). Body density was estimated via subcutaneous fat measurements [15] made using skinfold callipers (Baty International, West Sussex, UK), and body fat percentage was then ascertained [16].

Participants were then taken to the university swimming pool to confirm swimming competence and to be familiarised with procedures in anticipation of main trials. For this, participants were asked to complete a 60 min intermittent swimming set which was to be performed during the exercise trial. In this familiarisation session participants were accustomed to wearing heart rate monitors

in the pool and taking recordings periodically. They were also familiarised with the ratings of perceived exertion scale [17].

After an interval of at least one week participants then completed two eight-hour trials (swimming and control) in a randomized-crossover fashion. Each trial was separated by at least one week. On the morning of main trials participants arrived at the laboratory having fasted overnight and not eaten breakfast. Main trials commenced at 09:00 with the consumption of a standard breakfast snack. This was consumed within 5 min. On the exercise trial participants rested within the laboratory for the first 40 min, after which they were escorted to the university swimming pool via motorised transport, in time for commencing swimming at the beginning of the second trial hour. At this time, participants began a 60 min intermittent swimming set. The set was composed of six 10 min blocks. In each block participants swam continuously for seven min using their preferred stroke and then rested for three min. The speed of swimming was ultimately determined by the participant although they were instructed to swim at a moderate intensity, defined as a rating of perceived exertion between 12 and 14. During exercise the distance completed was recorded. Heart rate was also assessed using short range telemetry. Upon completion of each swimming block participants rested on the pool side with their legs immersed in the water. Ratings of perceived exertion were then assessed. After completing the swimming protocol participants were escorted back to the research laboratory where they rested for a further six hours. Identical procedures were completed in the control trial except that no exercise was performed. Instead, during the equivalent time period resting metabolic rate was assessed via indirect calorimetry in order to permit the calculation of net energy expenditure (gross energy expenditure minus resting energy expenditure) during exercise.

**2.3. Physical Activity and Dietary Standardization.** Participants completed a weighed food record of all items consumed within the 24 h preceding their first main trial. Alcohol and caffeine were not permitted during this period. This feeding pattern was replicated prior to the second main trial. Participants refrained from strenuous physical activity during this time.

**2.4. Appetite and Environmental Conditions.** At baseline, 0.5-hour, 1-hour, and 30 min intervals thereafter appetite perceptions (hunger, satisfaction, fullness, and prospective food consumption) were assessed using 100 mm visual analogue scales [18]. Environmental temperature and humidity were also measured at these times using a handheld hygrometer (Omega RH85, Manchester, UK). The temperature of the swimming pool was monitored using a glass thermometer (Fisher Scientific, UK).

**2.5. Breakfast and Ad Libitum Buffet Meals.** During each main trial all food was consumed within the research laboratory and was quantified by the investigators. Main trials commenced with breakfast consumption ( $\sim 09:00$ ). The breakfast provided was standardised to body weight

and consisted of a commercial cereal bar (Kellogg's Nutri-grain). Participants received 1.06 g per kilogram of body weight measured on the first trial visit. Identical amounts were consumed across trials. For a 70 kg individual this provided 1092 kJ of energy, 6 g of fat, 4 g of protein, and 48 g of carbohydrate.

At 3 h (~12:00) and 7.5 h (~16:30) into trials participants were given access to a buffet meal for a period of 30 min from which they could consume food *ad libitum*. The buffet meal provided diversity in protein, fat, and carbohydrate content in order to facilitate the detection of macronutrient preferences (Table 3). Food was presented in excess of expected consumption. Participants were told to eat until satisfied and that additional food was available if desired. Participants consumed meals in isolation so that social influence did not constrain food selection. Food consumption was ascertained by examining the weighted difference in each food item remaining compared with the weight of that initially presented. The energy and macronutrient content of the items consumed was ascertained using manufacturer values.

**2.6. Acylated Ghrelin.** To explore the effects of swimming on circulating concentrations of acylated ghrelin, blood samples were collected from 10 of the 14 participants at baseline, 1 h (pre-exercise), 2 h (post-exercise), 3 h, 4 h, 6 h, and 7.5 h. (We did not measure acylated ghrelin in four participants for logistical reasons, i.e., the room we used for blood sampling at the swimming pool was not always available). In both the swimming and control trials baseline samples and the equivalent pre- and postexercise blood samples were taken via venepuncture of an antecubital vein. Thereafter, the remaining samples were collected via a cannula (Venflon, Becton Dickinson, Helsingborg, Sweden) positioned in an antecubital vein. Details of sample preparation, collection, and analysis have been described in depth previously [12, 14]. The within batch coefficient of variation for the acylated ghrelin ELISA assay was 6.4%.

**2.7. Energy Expenditure Estimation.** Energy expenditure during swimming was estimated using equations based on multiples of resting metabolism (METs) [19]. Specifically, energy expenditure was estimated by multiplying each participant's estimated resting energy expenditure ( $\text{kJ}\cdot\text{min}^{-1}$ ) in the control trial by an appropriate MET value for the stroke used during each seven-minute block of swimming: general breast stroke (10 METs), general backstroke (7 METs), slow crawl ( $\leq 0.95 \text{ m}\cdot\text{s}^{-1}$ —8.0 METs), and fast crawl ( $> 0.95 \text{ m}\cdot\text{s}^{-1}$ —11 METs).

**2.8. Statistical Analysis.** All data was analyzed using the Statistical Package for the Social Sciences (SPSS) software version 16.0 for Windows (SPSS Inc, Chicago, IL, US.). Area under the concentration versus time curve calculations were performed using the trapezoidal method. Student's *t*-tests for correlated data were used to assess differences between fasting and area under the curve values for appetite perceptions, acylated ghrelin, temperature, and humidity between

the control and swimming trials. Repeated measures, two-factor ANOVA was used to examine differences between the swimming and control trials over time for appetite perceptions, energy and macronutrient intake, and acylated ghrelin. The Pearson product moment correlation coefficient was used to examine relationships between variables. Correction of acylated ghrelin values for changes in plasma volume did not alter the statistical significance of findings therefore for simplicity the unadjusted values are presented. Statistical significance was accepted at the 5% level. Results are presented as mean  $\pm$  SEM. A power calculation indicated that 13 participants were needed to provide sufficient power (80%) to detect a 50% compensation in energy intake with alpha set at 5%.

### 3. Results

**3.1. Exercise Responses and Resting Oxygen Consumption.** During the 42 min of swimming ( $6 \times 7$  min intervals) the mean distance completed was  $1875 \pm 156$  m. The mean swimming speed performed was  $0.74 \pm 0.1 \text{ m}\cdot\text{s}^{-1}$ , and this elicited an estimated net energy expenditure (exercise minus resting) of  $1921 \pm 83$  kJ. The corresponding mean heart rate and rating of perceived exertion values during the sessions were  $155 \pm 5 \text{ beats}\cdot\text{min}^{-1}$  and  $14 \pm 0$ . To complete the swimming session four participants swam breaststroke for all of the intervals whilst three participants used only front crawl and two participants used only backstroke. Three participants used a combination of front crawl and breast stroke whilst two participants alternated between breaststroke and backstroke. Participants' mean oxygen consumption at rest during the second hour of the control trial (i.e., the time when they were swimming during the exercise trial) was  $0.32 \pm 0.01 \text{ L}\cdot\text{min}^{-1}$  ( $6.5 \pm 0.3 \text{ kJ}\cdot\text{min}^{-1}$ ).

**3.2. Baseline Parameters.** No between-trial differences existed at baseline for any of the ratings of appetite assessed or in plasma concentrations of acylated ghrelin (student's *t*-test,  $P > .05$  for each).

**3.3. Appetite, Energy and Macronutrient Intake.** Perceived ratings of hunger and prospective food consumption were suppressed during and immediately after swimming before increasing above values exhibited during the control trial in the hours after exercise (two-factor ANOVA, trial  $\times$  time interaction;  $P < .05$  for each). Conversely, perceived ratings of fullness and satisfaction were increased transiently during swimming before decreasing below control values in the hours thereafter (two-factor ANOVA, trial  $\times$  time interaction;  $P < .05$  for each) (Figure 1). Analysis of the appetite area under the curve (AUC) data confirmed these results. After the morning meal the hunger AUC (3.5–8 h) was significantly higher in the swimming trial as compared with control (swimming  $178 \pm 20$ , control  $152 \pm 19$ ; student's *t*-test,  $P = .028$ ) whilst fullness tended to be reduced (swimming  $227 \pm 21$ , control  $243 \pm 17$ ; student's *t*-test,  $P = .052$ ). Moreover, from baseline to consumption of the morning buffet meal the fullness AUC (0–3 h) was

TABLE 1: Energy intake (kJ) in the control and swimming trials ( $n = 14$ ). There were no significant differences between the swimming and control trials ( $P > .05$ ).

	Control	Swimming
Morning meal (3–3.5 h)	5517 ± 434	5856 ± 403
Afternoon meal (7.5–8 h)	3644 ± 459	3893 ± 577
Total trial	9161 ± 719	9749 ± 809

TABLE 2: Macronutrient intake in the control and swimming trials. Values are gram and (%) ( $n = 14$ ). There were no significant differences between the swimming and control trials ( $P > .05$ ).

Control trial	Fat	Carbohydrate	Protein
Morning meal (3–3.5 h)	54 ± 5 (34.1)	156 ± 11 (49.1)	59 ± 9 (16.8)
Afternoon meal (7.5–8 h)	33 ± 5 (33.8)	107 ± 15 (49.9)	38 ± 8 (16.3)
Total Trial	87 ± 8 (34.9)	263 ± 21 (49.1)	97 ± 9 (16.0)
Swimming trial	Fat	Carbohydrate	Protein
Morning meal (3–3.5 h)	55 ± 5 (34.0)	164 ± 12 (49.3)	60 ± 8 (16.7)
Afternoon meal (7.5–8 h)	35 ± 5 (33.1)	117 ± 20 (50.2)	38 ± 7 (16.7)
Total Trial	90 ± 9 (34.2)	281 ± 26 (49.4)	98 ± 9 (16.4)

significantly higher in the swimming trial as compared with control (swimming  $74 \pm 12$ , control  $54 \pm 8$ ; student's  $t$ -test,  $P = .025$ ) whilst prospective food consumption was suppressed (swimming  $221 \pm 12$ , control  $231 \pm 11$ ;  $P = .049$ ).

Energy intake was significantly higher at the morning buffet meals compared with the afternoon meals (two-factor ANOVA, main effect of time;  $P = .003$ ); however, there were no between-trial differences in energy intake at either feeding opportunity (two-factor ANOVA, trial and interaction main effects;  $P > .05$  for each). Relative energy intake (energy intake—net energy cost of exercise) was therefore significantly lower on the swimming trial as compared with control (swimming  $7828 \pm 774$  kJ, control  $9163 \pm 720$ ). Table 1 presents the energy intake data for the control and swimming trials.

Two-factor ANOVA showed no trial or interaction (trial  $\times$  time) main effects for macronutrient intake (absolute amount or percentage intake) indicating that no significant differences existed between trials for the intake of fat, carbohydrate or protein (Table 2).

**3.4. Acylated Ghrelin.** Data for ten participants showed that plasma concentrations of acylated ghrelin were suppressed during swimming and after consumption of the morning buffet meal (two-factor ANOVA, main effect of trial;  $P =$

TABLE 3: Items presented at buffet meals.

Coco-pops—Cereal
Cornflakes—Cereal
Rice Krispies—Cereal
Frosties—Cereal
Milk
Cereal Bar
White Bread
Brown Bread
Tuna
Cheese
Ham
Butter
Mayonnaise
Salted Crisps
Apple
Orange
Banana
Chocolate rolls
Chocolate muffins
Plain muffins
Cookies
Chocolate bar (Mars fun size)

.038). On closer inspection of the data one participant was a clear outlier exhibiting fasting values on both trials which were approximately nine times (26 standard deviations) higher than the mean fasting values of the other nine participants ( $949 \text{ pg}\cdot\text{mL}^{-1}$  for the outlier versus  $108 \pm 10 \text{ pg}\cdot\text{mL}^{-1}$  for the mean ( $\pm$ SEM) of the other nine participants). Upon removal of this outlier the suppression of acylated ghrelin at the end of the swimming bout and after the first meal on each trial is displayed with greater clarity (two-factor ANOVA, trial  $\times$  time interaction;  $P < .001$ ) (Figure 2). Examination of the acylated ghrelin AUC (outlier excluded,  $n = 9$ ) confirmed suppressed concentrations of acylated ghrelin prior to the first buffet meal (0–3 h) on the swimming trial (swimming  $473 \pm 232$ , control  $505 \pm 217 \text{ pg}\cdot\text{mL}^{-1}\cdot 3 \text{ h}$ ) (student's  $t$ -test,  $P < .001$ ).

To examine the relationship between acylated ghrelin and energy intake, at both the morning and afternoon buffet meals correlations were performed between acylated ghrelin values immediately prior to each meal and subsequent energy intake. Moreover, correlations were also performed using the acylated ghrelin AUC leading up to the morning (0–3 h AUC) and afternoon (3–8 h AUC) buffet meals. In all instances no significant relationships were found between acylated ghrelin and energy intake.

**3.5. Body Mass, Fluid Intake, and Environmental Conditions.** There were no significant differences between the control and swimming trials (all  $P > .05$ ) in body weight (control  $76.7 \pm 2.1$ , swimming  $76.5 \pm 2.2$  kg), water intake (control  $1402 \pm 219$ , swimming  $1302 \pm 226$  mL) laboratory atmospheric

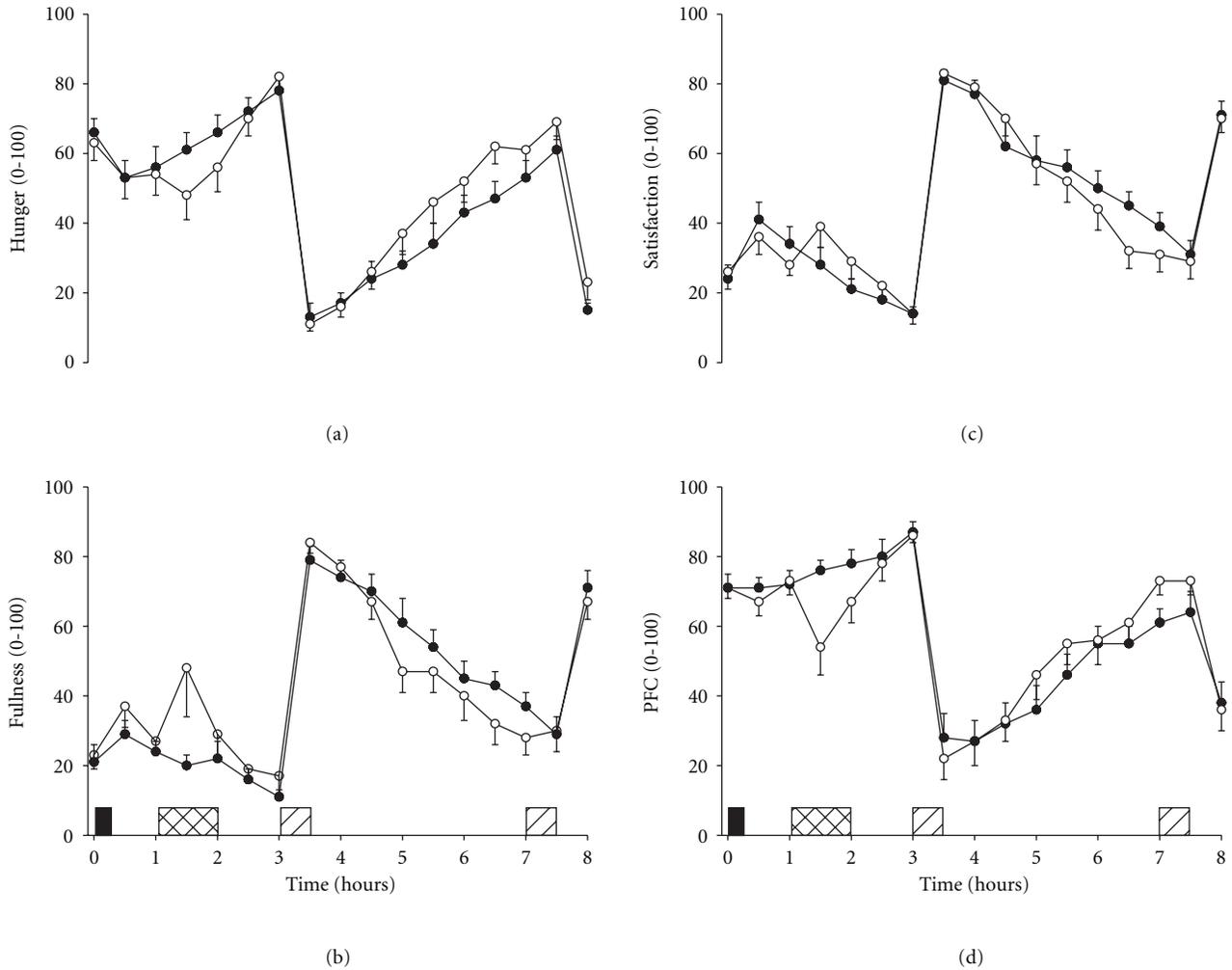


FIGURE 1: Ratings of hunger (a), fullness (b), satisfaction (c), and prospective food consumption (d) in the swimming ( $\circ$ ) and control ( $\bullet$ ) trials. Values are mean  $\pm$  SEM ( $n = 14$ ). Black rectangle indicates breakfast snack, hatched rectangle indicates swimming, and diagonal rectangles indicate buffet meals. Two-factor ANOVA revealed a trial  $\times$  time interaction effect for each ( $P < .05$ ).

temperature (control  $21.6 \pm 0.3$ , swimming  $21.4 \pm 0.3^\circ\text{C}$ ), and relative humidity (control  $37.8 \pm 4.1$ , swimming  $37.8 \pm 4.1\%$ ). The atmospheric temperature and relative humidity at the swimming pool were  $26.4 \pm 0.8^\circ\text{C}$  and  $50.9 \pm 1.7\%$ , respectively. The temperature of the swimming pool water was  $28.1 \pm 0.1^\circ\text{C}$ .

#### 4. Discussion

The main findings arising from this investigation are three-fold. Firstly, moderate intensity swimming exhibited a biphasic influence on appetite with an inhibition existent during exercise and a later stimulation in the hours thereafter. Secondly, swimming did not influence *ad libitum* energy or macronutrient intake. Finally, our exploratory analyses showed that swimming transiently suppressed circulating concentrations of the orexigenic peptide, acylated ghrelin; however, no effects were apparent after exercise. This outcome indicates that acylated ghrelin does not mediate the reported stimulation of appetite after swimming.

The suppression of appetite (decreased hunger and prospective food consumption/elevated satisfaction and fullness) observed during swimming is a novel finding yet is consistent with previous research showing a transient inhibition of appetite resulting from land-based exercise modalities such as running and cycling [20, 21]. This phenomenon has been termed exercise-induced anorexia [22] and has been consistently observed during land-based activities performed at moderate intensities or higher ( $>60\%$   $\text{VO}_2$  max). Broom et al. [12] reported suppressed hunger and plasma acylated ghrelin during treadmill running and suggested a potential role of acylated ghrelin in determining suppressed appetite during exercise. The findings from the present study confirm that acylated ghrelin and appetite are concomitantly suppressed during swimming; however, the absence of any significant correlations between acylated ghrelin and any of the appetite markers assessed, during exercise or immediately after, suggests that there may not be a strong association between these variables. Given the diversity of the role of ghrelin in human physiology [23] it is possible that

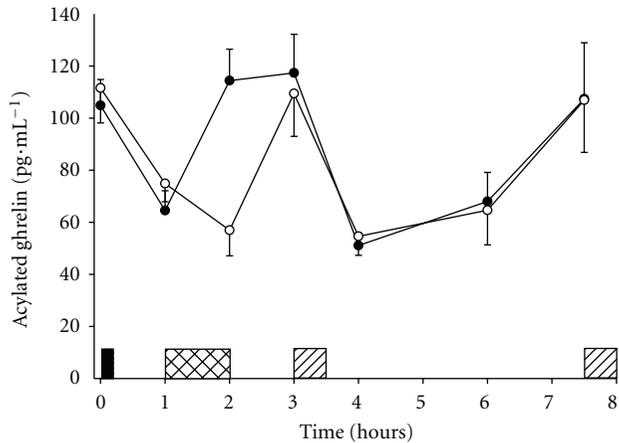


FIGURE 2: Plasma concentrations of acylated ghrelin in the swimming (○) and control (●) trials. Values are mean  $\pm$  SEM ( $n = 9$ ). Black rectangle indicates breakfast snack, hatched rectangle indicates swimming, diagonal rectangles indicate buffet meals. Two-factor ANOVA revealed a significant trial  $\times$  time interaction effect ( $P < .001$ ).

the transient suppression of circulating acylated ghrelin observed during exercise is entirely unrelated to appetite regulation. At present though, the physiological relevance of this response is not known.

In the hours after consumption of the morning buffet meal, ratings of hunger and prospective food consumption were higher in the swimming trial than the control trial whilst ratings of fullness were reduced. These findings indicate that swimming stimulated a delayed increase in appetite. This response is contrary to research which has examined appetite responses to land-based activities which have typically shown no acute compensation in appetite after performing exercise, even when significant amounts of energy are expended [20–22, 24]. The mechanism responsible for these discrepant findings is not immediately clear. It has been suggested that changes in body temperature may be important [5, 6]; however, this is unlikely in the present study as appetite was not stimulated until more than two hours after swimming. By this time core temperature would almost certainly have normalised. White et al. [5] speculate that the cooling and then subsequent reheating of the body may be associated with the release of “certain hormones” which stimulate the appetite. In the present study we measured circulating concentrations of acylated ghrelin, a peptide responsible for stimulating appetite and food intake [25, 26]. The present findings suggest that acylated ghrelin is not responsible for the augmented appetite response after swimming as circulating concentrations were not different from control after the morning buffet meal. It remains possible that compensatory changes in fasting or meal-related acylated ghrelin profiles may occur over a longer duration; however, further work is needed to examine this. It must also be considered that appetite is regulated on an acute basis by many circulating peptides in addition to acylated ghrelin, including peptide YY, pancreatic polypeptide, and

glucagon-like peptide-1 [10]. It is therefore feasible that changes in these peptides may have influenced the acylated ghrelin and appetite responses observed.

Research indicates that swimming may be less effective than land-based activities for inducing weight loss or reductions in body fat [3, 4]. Consistent with this, it has been observed that levels of adiposity are typically higher in swimmers than equal calibre runners [27, 28]. It has been suggested that an unparalleled stimulation of appetite and energy intake after swimming may explain these findings [6]. Despite the changes in appetite observed, the present investigation did not find any significant differences in energy or macronutrient intake between the swimming and control trials, either during the morning or afternoon meals. These findings are difficult to reconcile. It is known that food intake is influenced by a host of physiological, environmental, psychological, and social factors, some of which are learned over time and are resistant to change [29]. In this study it seems that the factors influencing appetite were insufficient to overcome other competing forces governing food intake. Nonetheless, as a consequence of the lack of change in energy intake, participants therefore failed to compensate for the energy expended during exercise and relative energy intake (energy intake—net energy cost of exercise) was subsequently lower on the swimming trial as compared with control (swimming  $7828 \pm 774$  kJ, control  $9163 \pm 720$  kJ; student's  $t$ -test,  $P = .008$ ). This outcome contradicts the suggestion that energy intake is augmented by swimming and therefore does not support the notion that swimming is an ineffective exercise modality for successful body weight control.

When comparing the present findings to previous data water temperature emerges as an important variable influencing food intake responses to exercise performed in water. White et al. [5] examined energy intake responses in healthy participants who performed cycling exercise while immersed in either cold water (20°C) or neutral water (33°C) and compared these responses to control responses (i.e., while resting in a dry environment). Energy intake was significantly higher after exercise in cold water (3653 kJ) as compared with the neutral water (2544 kJ) and the resting trials (2586 kJ). These results indicate that exercise in cold water stimulates energy intake. In similar fashion, Dressendorfer [7] submitted six trained males to 30 min of modified cycling in cold water (22°C), warm water (34°C), cycling on land, and a resting control trial. Participants consumed significantly more energy in the cold water trial than all other trials at a buffet meal provided immediately after exercise. Furthermore, energy intake in the warm water trial was significantly less than all other trials. Collectively, these findings suggest that water temperature and possibly subsequent core body temperature are important determinants of feeding responses after exercise in water. Despite these established findings, no study has previously examined the specific effects of swimming (rather than modified cycling) on appetite and food intake. Our findings appear to support the notion that exercise only in cold water stimulates food intake because in the present study the water temperature was moderate (28–28.5°C) and no change in energy intake was observed. The idea that exercise only in cold water

stimulates food intake is also supported by the finding that metabolic rate (and hence energy expenditure) is not increased by immersion in water at a temperature of 32°C (not that dissimilar from the temperature of the water in the present study) whereas metabolic rate is increased by immersion in cold water (either 14°C or 20°C) [30] and by cold air, possibly due to activation of brown adipose tissue [31]. It might be anticipated that immersion in water will only increase appetite and food intake if the water temperature lowers core temperature, eliciting an increase in metabolic rate either by shivering or nonshivering thermogenesis although this is speculation. Unfortunately core temperature was not assessed in the present study, therefore the exact relationship between this variable and energy intake cannot be explored. Further work is needed to examine this issue.

This investigation has some notable limitations. Firstly, an immersed, resting control trial was not included therefore making it difficult to determine whether the reported increase in appetite was due to immersion in water or the physical work completed. Despite this, the majority of previous investigations which have examined appetite responses to exercise have not observed increases in appetite afterwards [9], thus we believe that our findings still offer novel, interesting data. Secondly, although we have examined energy/macronutrient intake responses over an extended period, it remains possible that changes may occur over a longer duration of time, for example, on the day after exercise. An even longer period of observation would be necessary in future studies to test this hypothesis. Thirdly, this study did not directly compare the effects of swimming with those of other modes of exercise and this limits the extent to which conclusions can be drawn in this regard. Finally, participants were young, healthy males and we do not know if these findings would generalise to other populations such as females, the elderly or overweight and obese individuals. Additional work is required to examine these issues, particularly in overweight individuals as it is within this population that findings hold the most clinical importance.

In conclusion, this investigation has shown that an acute bout of moderate intensity swimming suppresses appetite during exercise before leading to an increase later on in the day. Despite this, energy intake and macronutrient selection appear resistant to change over the duration of time examined. Circulating concentrations of acylated ghrelin were suppressed during swimming and this may possibly have contributed to the reduction in appetite observed. Nonetheless, acylated ghrelin does not appear to mediate the reported increase in appetite in the hours after exercise. These findings provide novel information regarding the influence of swimming on the acute regulation of energy homeostasis.

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## Research Article

# Acute Impact of Moderate-Intensity and Vigorous-Intensity Exercise Bouts on Daily Physical Activity Energy Expenditure in Postmenopausal Women

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This study determined whether performing a single moderate- or vigorous-intensity exercise bout impacts daily physical activity energy expenditure (PAEE, by accelerometer). Overweight/obese postmenopausal women underwent a 5-month caloric restriction and moderate- ( $n = 18$ ) or vigorous-intensity ( $n = 18$ ) center-based aerobic exercise intervention. During the last month of intervention, in women performing moderate-intensity exercise, PAEE on days with exercise ( $577.7 \pm 219.7 \text{ kcal}\cdot\text{d}^{-1}$ ) was higher ( $P = .011$ ) than on days without exercise ( $450.7 \pm 140.5 \text{ kcal}\cdot\text{d}^{-1}$ ); however, the difference ( $127.0 \pm 188.1 \text{ kcal}\cdot\text{d}^{-1}$ ) was much lower than the energy expended during exercise. In women performing vigorous-intensity exercise, PAEE on days with exercise ( $450.6 \pm 153.6 \text{ kcal}\cdot\text{d}^{-1}$ ) was lower ( $P = .047$ ) than on days without exercise ( $519.2 \pm 127.4 \text{ kcal}\cdot\text{d}^{-1}$ ). Thus, women expended more energy on physical activities outside of prescribed exercise on days they did NOT perform center-based exercise, especially if the prescribed exercise was of a higher intensity.

## 1. Introduction

Obesity is associated with numerous chronic diseases and, currently, its prevalence is 34% in US adults [1]. Excess fat storage is the result of greater energy intake than expenditure for a period of time; thus, increasing energy expenditure is an important strategy to treat obesity. Approximately 20–45% of total daily energy expenditure is due to physical activity [2]. Physical activity energy expenditure (PAEE) can be further divided into energy expended during structured exercise and during activities of daily living other than structured exercise [2].

There has been extensive research investigating the effects of various exercise and/or caloric restriction interventions for inducing weight loss. In general, these programs are successful at inducing weight loss; however, there is some

evidence showing that increases in total daily energy expenditure during prescribed exercise interventions are less than expected given the amount of energy expended during the prescribed exercise sessions [3–8]. In support of this, one study showed that accelerometer counts from physical activities outside of structured exercise decreased by 8% after a 12-week training period [8]. This suggests that PAEE outside of the structured exercise may decrease as a result of the exercise treatment.

All of these prior studies examined the chronic or longer-term effects of exercise interventions on PAEE. However, it is also important to determine whether there are potential changes in PAEE acutely on days in which the exercise is performed. Yet, to date, only one small study examined this acute effect of exercise on daily PAEE [8]. It reported that accelerometer counts from nonexercise activities were lower

on days with, than without, structured exercise during a 12-week exercise program. Thus, the purpose of the present study was to determine whether performing a single exercise bout impacts daily PAEE in postmenopausal women and to determine whether the intensity of the exercise bout plays a role in any potential changes in daily PAEE.

## 2. Methods

**2.1. Study Design and Participants.** Women in this study are a subset of those enrolled in a randomized clinical trial that was designed to determine whether intensity of aerobic exercise affects the loss of abdominal adipose tissue and improvement in cardiovascular disease risk factors in postmenopausal women with abdominal obesity (ClinicalTrials.gov: NCT00664729). The detailed inclusion and exclusion criteria were published previously [9]. Briefly, they were: (1) older postmenopausal (age: 50–70 yr), (2) overweight or obese (BMI: 25–40 kg·m<sup>-2</sup> and waist circumference >88 cm), (3) nonsmoking, (4) not on hormone therapy, and (5) sedentary (<15 minutes of exercise, two times per wk) in the past 6 months before enrollment. The study was approved by the Wake Forest University Institutional Review Board, and all women signed an informed consent form to participate in the study according to the guidelines for human research.

Data used for the current analyses are from women who were randomized to caloric restriction plus moderate-intensity aerobic exercise (moderate-intensity) or caloric restriction plus vigorous-intensity aerobic exercise (vigorous-intensity) and completed the study interventions. There were 18 women in the moderate-intensity and 18 women in the vigorous-intensity groups who had PAEE data available from before the intervention and from days with and without center-based exercise in the last month of intervention.

**2.2. Intervention.** Both the moderate-intensity and vigorous-intensity interventions were 5 months, and the energy deficit was designed to be approximately 2100 kcal·wk<sup>-1</sup> from caloric restriction and 700 kcal·wk<sup>-1</sup> from center-based exercise. Individual energy needs for weight maintenance were calculated from each woman's resting metabolic rate (indirect calorimetry after an overnight fast by using a MedGraphics CCM/D cart and BREEZE 6.2 software, MedGraphics, St. Paul, MN) and an activity factor based on self-reported daily activity (1.2–1.3 for sedentary lifestyle).

Individual diets were developed by a registered dietitian according to each woman's choices from a menu designed by a registered dietitian. Throughout the course of the 5-month intervention, all women were provided with daily lunch, dinner, and snacks prepared by the General Clinical Research Center (GCRC) metabolic kitchen. Women purchased and prepared their breakfast meals from a provided menu plan. They were asked to eat only the food that was given to them or that was approved from the breakfast menu. Energy make-up of the diet was approximately 25% from fat, 15% from protein, and 60% from carbohydrate. Women were allowed

to consume as many noncaloric, noncaffeinated beverages as they liked. They were also allowed 2 free days per month during which they were not provided food but were given guidelines for diet intake at their prescribed energy level. All women were provided with daily calcium supplements (500 mg, 2 times·d<sup>-1</sup>). They were asked to keep a log of all foods consumed, and the records were monitored by the dietitian to verify compliance.

The exercise interventions were center-based walking on treadmills (LifeFitness 9500HR, Life Fitness Co., IL) on 3 d·wk<sup>-1</sup> under the supervision of an exercise physiologist. Exercise progressed from 20–25 min the first week to 55 minutes by the end of the sixth week for the moderate-intensity (45–50% of maximum oxygen consumption, VO<sub>2</sub>max) group and it progressed from 10–15 minutes the first week to 30 min by the end of the sixth week for the vigorous-intensity (70–75% of VO<sub>2</sub>max) group. The target exercise intensity was determined based on each woman's target heart rate calculated from the Karvonen equation [(HRR × intensity) + resting heart rate] [10], where HRR is the maximal heart rate, obtained from each woman's maximum exercise test, minus resting heart rate. Treadmill speed and grade were adjusted on an individual basis to ensure women exercised at their prescribed exercise intensity. Blood pressure was taken before and after each exercise session. Heart rate readings (by Polar heart rate monitors; Polar Electro Inc, Lake Success, NY) were taken before, at least 2 times during (to monitor compliance to the prescribed exercise intensity), and after the exercise.

**2.3. Physical Activity Energy Expenditure (PAEE) Measurements.** PAEE was measured using an RT3 triaxial accelerometer (Stayhealthy, Inc., Monrovia, CA). It is about the size of a pager and is worn by clipping onto the waist. It collects 3-dimensional data at one minute intervals and stores such data for 7 days. Data were collected in units of acceleration. Activity energy expenditure was computed using the manufacturer's software from the integrated acceleration and body mass with formula developed by the manufacturer. Daily PAEE was calculated using the average calories expended per minute times 1440 minutes a day.

Women were asked to wear the accelerometer before and each month during the intervention, for 5–7 days including week days and weekend days. Women were instructed not to change their activities while wearing the accelerometer at all times, except while sleeping and bathing. Data collected from RT3 monitors were included only when there were valid data from both before the intervention and during the last month of intervention. During the last month of intervention, RT3 data were considered valid when data were collected from at least 2 days with center-based exercise and at least 2 days without center-based exercise. The average PAEE from days with and without center-based exercise were used for the current analyses. Of note, the average daily PAEE from days with center-based exercise included the energy expended during the exercise sessions, and none of the women performed structured exercise at baseline.

Treadmill readings during the exercise sessions were recorded for each woman as a measure of energy expended during center-based exercise. Height and weight were measured before and after the 5-month intervention with shoes and jackets or outer garments removed.

**2.4. Statistics.** All analyses were performed using SAS software, version 9.1 (SAS Institute, Cary, NC). Continuous variables are presented as mean  $\pm$  SD. Analysis of variance was used to compare values between groups. Paired *t*-tests were used to compare values within the same group at different measurement points. An alpha level of 0.05 was used to denote statistical significance.

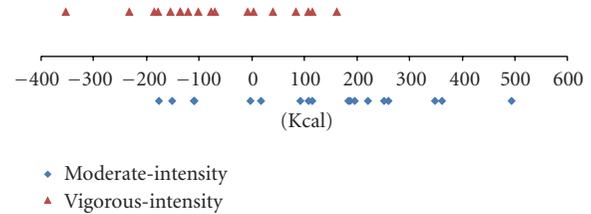
### 3. Results

As shown in Table 1, there were no differences in baseline characteristics such as age, racial distribution, body weight, and body mass index between the moderate-intensity and vigorous-intensity groups. Daily PAEE was also similar between the two groups at baseline.

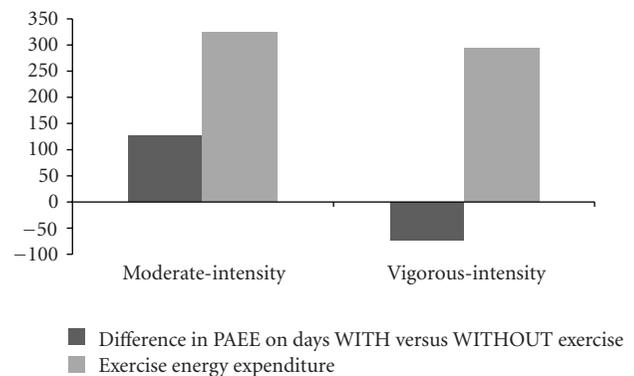
The total amount of weight loss during intervention was similar between the moderate-intensity and vigorous-intensity groups ( $12.9 \pm 4.2$  kg or  $14.6 \pm 4.8\%$  and  $12.6 \pm 5.1$  kg or  $13.5 \pm 4.6\%$ , resp.). During the last month of intervention, PAEE on days with center-based exercise was significantly higher in women performing moderate-intensity exercise than in women performing vigorous-intensity exercise ( $P = .052$ ). In contrast, PAEE on days without exercise was not statistically different between the two groups ( $P = .135$ ).

In the moderate-intensity group, 13 of the 18 women had higher PAEE on days with than without center-based exercise (Figure 1), and the average PAEE on days with exercise ( $577.7 \pm 219.7$  kcal $\cdot$ d $^{-1}$ ) was higher than on days without exercise ( $450.7 \pm 140.5$  kcal $\cdot$ d $^{-1}$ ,  $P = .011$ ) (Table 1). Yet, the difference ( $127.0 \pm 188.1$  kcal $\cdot$ d $^{-1}$ ) was much smaller than the energy expended during exercise ( $325.0 \pm 79.6$  kcal $\cdot$ d $^{-1}$ ) (Figure 2), suggesting that, during the 5th month of exercise training, women expended less energy on activities outside of the structured exercise when they exercised during the day. In support of this, PAEE on days with center-based exercise was not different from baseline PAEE ( $520.8 \pm 206.5$  kcal $\cdot$ d $^{-1}$ ;  $P > .05$  for both) in women performing moderate-intensity exercise even though energy expended during exercise was included in the daily PAEE on days with exercise.

On the other hand, in the vigorous-intensity group, 12 of the 18 women had lower PAEE on days with than without center-based exercise during the last month of the intervention (Figure 1). The average daily PAEE on days with exercise ( $450.6 \pm 153.6$  kcal $\cdot$ d $^{-1}$ ) was lower than on days without exercise ( $519.2 \pm 127.4$  kcal $\cdot$ d $^{-1}$ ) (difference =  $-68.6 \pm 136.1$  kcal $\cdot$ d $^{-1}$ ,  $P = .047$ ) again even though energy expended during exercise ( $296.8 \pm 93.0$  kcal $\cdot$ d $^{-1}$ ) was included in daily PAEE on days with exercise (Figure 2). This indicates that, during the 5th month of exercise training, women performing vigorous-intensity exercise were expending more total calories on nonexercise days than on exercise



**FIGURE 1:** The difference between daily physical activity energy expenditure during days with and without center-based exercise (PAEE on days WITH exercise minus PAEE on days WITHOUT exercise). In the moderate-intensity exercise (moderate-intensity) group, majority of the women had higher PAEE during days WITH center-based exercise. In contrast, in the vigorous-intensity exercise (vigorous-intensity) group, majority of the women had higher PAEE during days WITHOUT center-based exercise.



**FIGURE 2:** The difference between daily physical activity energy expenditure during days with and without center-based exercise (PAEE on days WITH exercise minus PAEE on days WITHOUT exercise) and energy expended during center-based exercise by group. In women performing moderate-intensity exercise (moderate-intensity), PAEE was higher on days with center-based exercise; however, the difference was much lower than the energy expended during exercise. In contrast, in women performing vigorous-intensity exercise (vigorous-intensity) group, PAEE was lower on days with center-based exercise, even with exercise energy expenditure included in PAEE.

days. In addition, PAEE on days without exercise was not different from baseline daily PAEE ( $543.2 \pm 164.0$  kcal $\cdot$ d $^{-1}$ ;  $P > .05$ ); however, PAEE on days with exercise (which included energy expended during center-based exercise) was significantly lower than baseline PAEE ( $P = .020$ ).

### 4. Discussion

This study adds information to the literature regarding how acute exercise sessions affect daily PAEE and whether the intensity of exercise influences the effects. We found that, during the last month of a 5-month moderate-intensity exercise training intervention, the daily PAEE during days WITH center-based exercise was higher than days WITHOUT exercise by an amount much smaller than the exercise energy expenditure. During the 5th month of

TABLE 1: Participant characteristics at baseline.

Characteristics	Moderate-intensity ( $n = 18$ )	Vigorous-intensity ( $n = 18$ )
Age (yrs)	58.7 $\pm$ 5.9	58.1 $\pm$ 5.4
Non-White (n, %)	6, 33.3%	4, 22.2%
Body weight (kg)	88.9 $\pm$ 8.5	91.1 $\pm$ 12.9
Body mass index ( $\text{kg}\cdot\text{m}^{-2}$ )	33.3 $\pm$ 3.1	33.3 $\pm$ 3.8
PAEE at baseline ( $\text{kcal}\cdot\text{d}^{-1}$ )	520.8 $\pm$ 206.5	543.2 $\pm$ 164.0
PAEE on days with exercise in last month ( $\text{kcal}\cdot\text{d}^{-1}$ )	577.7 $\pm$ 219.7	450.6 $\pm$ 153.6*
PAEE on days without exercise in last month ( $\text{kcal}\cdot\text{d}^{-1}$ )	450.7 $\pm$ 140.5 <sup>†</sup>	519.2 $\pm$ 127.4 <sup>‡</sup>

PAEE: physical activity energy expenditure.

\* $P = .052$  versus moderate-intensity group; <sup>†</sup> $P = .011$  versus PAEE on days with exercise in last month; <sup>‡</sup> $P = .047$  versus PAEE on days with exercise in last month.

a vigorous-intensity exercise training intervention, daily PAEE during days WITH center-based exercise was lower than days WITHOUT center-based exercise sessions, even with energy expended during the exercise sessions included in PAEE. Therefore, there was a reduction in PAEE outside of the center-based exercise sessions in both intervention groups, and this reduction appeared to differ based on the intensity level of the center-based exercise because it was greater in women performing vigorous-intensity, compared to moderate-intensity, exercise.

Our findings are in line with those of Meijer et al. [8], who found that accelerometer counts of total physical activity were similar between days with and without training, and that after energy expenditure during the training session was subtracted out, accelerometer counts were significantly lower on training days. In their study, the training program included one aerobic exercise of 60 minutes and one cardio- and weight-stack machine exercise of 90 minutes each week for 12 weeks in men and women of 55 years and older. We cannot directly compare the magnitude of the PAEE responses in our study to their study because the intensity of the exercises was not specified and only accelerometer counts were reported in their study.

We also showed that exercise at vigorous intensity induced greater compensation in PAEE than moderate-intensity exercise. Of note, both exercise programs in our study are consistent with the current physical activity guidelines for adults [11, 12]. The frequency of the exercise sessions was the same for the moderate-intensity and vigorous-intensity exercise groups, and the volume of exercise was also similar. However, this does not exclude the possibility that volume or frequency of exercise of an exercise program may affect the “chronic” response in PAEE to the program. Further studies are needed to address these questions because these are important factors to consider when designing exercise programs to better meet an individual’s goal for participating exercise.

In this study, PAEE was measured in the last month of the 5-month training program. Thus, women were relatively trained so that PAEE responses to acute exercise may be somewhat different from those if women were untrained. However, we suspect that the compensation in PAEE is likely lower in the trained state. In other words, for a person who does not participate in regular exercise, an acute session

of exercise may induce greater compensation in PAEE. On the other hand, the information found in this study may be more important because with the epidemic of obesity, many individuals participating in exercise programs may think that would satisfy the goal of weight control. Thus, we should educate and encourage them to maintain higher daily activities while participating in exercise programs at the same time.

The results of this study should be interpreted in light of a few considerations. The daily PAEE during days with and without center-based exercises was the average of at least two days. Although this provides a good measure of activity energy expenditure, it would be better if data from more days were available. Second, all exercise sessions were during the week. For PAEE during days without exercise, we did not have enough data to determine whether there was a difference in PAEE between those weekdays and weekend days. Third, we used treadmill readings as the energy expended during exercise sessions. These are not accurate measures of energy expenditure; however, we believe this will not affect our conclusion given the big difference shown between exercise energy expenditure and the difference between PAEE during days with and without exercise sessions (Figure 2).

In summary, the main finding of this study is that women expended more energy during physical activities outside of prescribed exercise sessions on days they did NOT perform center-based exercise, especially if the prescribed exercise was of a higher intensity. More research is needed to determine what exercise prescription can minimize this “compensation”. This phenomenon may have biological and behavioral reasons, and future research investigating the underlying mechanisms is warranted. Thus, health professionals should encourage individuals who are participating in exercise programs to maintain levels of activity in addition to the program, so that greater weight loss can be achieved.

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## Research Article

# Impact of Weight Loss on Physical Function with Changes in Strength, Muscle Mass, and Muscle Fat Infiltration in Overweight to Moderately Obese Older Adults: A Randomized Clinical Trial

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*Purpose.* Evaluate the effects of weight loss on muscle mass and area, muscle fat infiltration, strength, and their association with physical function. *Methods.* Thirty-six overweight to moderately obese, sedentary older adults were randomized into either a physical activity plus weight loss (PA+WL) or physical activity plus successful aging health education (PA+SA) program. Measurements included body composition by dual-energy X-ray absorptiometry, computerized tomography, knee extensor strength, and short physical performance battery (SPPB). *Results.* At 6 months, PA+WL lost greater thigh fat and muscle area compared to PA+SA. PA+WL lost 12.4% strength; PA+SA lost 1.0%. Muscle fat infiltration decreased significantly in PA+WL and PA+SA. Thigh fat area decreased 6-fold in comparison to lean area in PA+WL. Change in total SPPB score was strongly inversely correlated with change in fat but not with change in lean or strength. *Conclusion.* Weight loss resulted in additional improvements in function over exercise alone, primarily due to loss of body fat.

## 1. Introduction

The prevalence of obesity in older adults has been rising steadily. In 2000, 22.9% of individuals between the ages of 60–69 and 15.5% of those ages 70 and older were classified as obese. These are increases of 56% and 36%, respectively, since 1991 [1]. Activities of daily living (ADL) impairment due to obesity are estimated to increase by 17.7% for men and 21.8% for woman from 2000 to 2020 if this obesity trend continues [2]. The rising prevalence of obesity and obesity-related ADL disability in older adults makes the prevention and “treatment” of obesity in older adults a very important public health issue.

In addition to obesity, the loss of muscle strength is an important independent risk factor for mortality [3] and

incident mobility limitation in older adults [4]. Sarcopenia, the loss of muscle mass with age, is thought to be the primary reason for age-related declines in muscle strength [5, 6]; however, loss of strength cannot exclusively be attributed to the loss of muscle mass [7]. Goodpaster et al. have shown in the Health, Aging and Body Composition (Health ABC) Study that an increase in muscle fat infiltration, manifested by decreased muscle density or attenuation values [8], is an important predictor of muscle strength independent of muscle mass [9].

Age-related declines in muscle strength, muscle mass, and muscle density can be attenuated or prevented with a regular structured physical activity program consisting of walking, resistance strength training, and balance training [10]. Additionally, it has been suggested that obesity

compounds the effects of sarcopenia on physical disability and impairment in older adults [11, 12]. This finding is problematic because the loss of muscle or lean mass is accelerated by weight loss (WL) in older adults [13]. However, it has been shown by Chomentowski et al. that this accelerated muscle loss can be attenuated with moderate aerobic exercise [14]. It has also been demonstrated that a WL intervention with moderate physical activity (PA) can improve physical function in older adults with knee osteoarthritis despite losing lean mass [15]. Furthermore, WL and regular PA have been shown to improve function in frail older adults [16]. A gap in knowledge is the combined effect of WL and PA compared with PA alone, on body composition, strength, and function in older adults. This is important because the loss of lean mass associated with WL could lead to the loss of strength, mobility, and function in the older adult population. The potential risks and benefits of weight loss in overweight to moderately obese older adults should be tested in the context of a physical activity program designed to optimally preserve body composition and improve mobility and function.

The primary aim of this study was to determine the effects of weight loss plus physical activity compared to physical activity with a successful aging (SA) health education program on function, muscle mass, muscle fat infiltration, and strength in older adults. Additionally, we examined the association between change in muscle mass, muscle fat infiltration, and fat mass with change in function and strength.

## 2. Materials and Methods

**2.1. Participants.** Community dwelling older men and woman age 60 and over, who were overweight to moderately obese (body mass index between 28.0 and 39.9 kg/m<sup>2</sup>) and living a sedentary lifestyle (formal exercise less than 3x/week for a total of less than 90 min/week), were recruited from the greater McKeesport, PA area to participate in a one-year randomized clinical trial. Initial eligibility criteria included the self-reported ability to walk 1/4 mile (2-3 blocks), completion of a 400-meter walk in less than 15 minutes without assistance from another person or the use of an assistive device, successful completion of a behavioral run-in, which included an activity log and food diary, the willingness to be randomized to either intervention group, as well as attend meetings and physical activity sessions in McKeesport, PA. Participants were excluded if they failed to provide informed consent, had diabetes requiring insulin, history of diabetic coma, uncontrolled diabetes (defined as a fasting blood sugar greater than 300 mg/dl), severe kidney disease that required dialysis, or severe hypertension (systolic blood pressure >180 mmHg or diastolic blood pressure >100 mmHg). Further, significant cognitive impairment (known diagnosis of dementia or a modified minimal state exam score <80), and other conditions impairing understanding and communication were also exclusions. Other significant comorbid disease severe enough to impair ability to participate in an exercise-based intervention resulted in exclusion. Any person

who developed chest pain or severe shortness of breath during 400 m walk test was also excluded. Participants were also ineligible if a member of their household was already enrolled in the study, if they were currently participating in another intervention trial, planned to move in the next year, had lost more than 10 pounds in the past 4 months, or were taking any drugs for the treatment of obesity.

Participants who met the above were randomly assigned into one of two intervention programs: physical activity plus weight loss (PA+WL) or physical activity plus a successful aging health education program (PA+SA). Randomization was done using a Microsoft Access-based random-number generating algorithm with stratification by age and sex to further ensure balance between groups (Microsoft Redmond, Washington). All of the methods described in this paper were implemented following approval by the University of Pittsburgh's Institutional Review Board.

**2.2. Physical Activity Program.** All participants, regardless of the randomized group assignment, participated in identical physical activity programs. The PA program combined aerobic, strength, balance, and flexibility exercises [17]. In brief, the PA program focused on treadmill walking of at least 150 min/wk as the primary mode of activity. To complement the walking, participants completed lower extremity resistance training, balance training exercises, and stretching.

The program was divided into three phases: adoption (weeks 1–8), transition (weeks 9–24), and maintenance (weeks 25–52), which were designed to gradually transition exercise out of the clinic setting and into the participant's daily routine. During the adoption phase, all participants were required to attend three center-based exercise sessions per week, which averaged 60 minutes per session. For the transition phase, center-based sessions were reduced to two sessions per week. During this phase, the center-based sessions were supplemented with one or more home-based sessions. The home-based sessions were to be similar to the center-based sessions. During the maintenance phase of the program, participants were invited to attend an optional exercise session at the center once per week, but were expected to engage in physical activity at least three times per week.

**2.3. Weight Loss Intervention.** Those randomized into the PA+WL arm participated in a healthy-eating WL intervention, in addition to the PA program described above. Participants attended 24 weekly, 2 bimonthly, and 5 monthly sessions, which were lead by the study nutritionist. During these meetings, strategies to achieve the recommended caloric intake were discussed and performance in the weight loss intervention was assessed. The nutritionist scheduled one-on-one sessions if a participant was having difficulty adhering to the WL intervention.

The WL intervention was designed to promote weight reduction and decrease lipid levels. The calorie and fat gram goals were developed by the Diabetes Prevention Program [18]. Based on baseline weight, participants were assigned

one of the following daily goals: 1200 calories and 33 fat grams, 1500 calories and 42 fat grams, 1800 calories and 50 fat grams, or 2000 calories and 55 fat grams. Total daily fat intake was limited to approximately 25% of total calories. An emphasis was put on the consumption of mono- and polyunsaturated fats while limiting saturated fat and cholesterol. In addition, participants were asked to include at least 5 servings of fruits or vegetables and 6 servings of grains, especially whole grains, in their daily diets. To ensure that participants met daily nutrient recommendations, age-appropriate multivitamin/mineral and calcium/vitamin D supplementation was recommended.

The goal of the WL intervention was a 7% reduction in body weight at the rate of 1 to 2 pounds per week during the first six months of the intervention. The goal for the remaining six months was to assist participants in achieving and maintaining their weight goal. Participants were required to keep food diaries at least six days per week during the first six months of the intervention and then for a minimum of once a month for the remainder of the study. Self-monitoring of caloric intake was emphasized and participants were encouraged to weigh themselves weekly at home. In addition, participants were weighed once a week by the study nutritionist at the start of the nutrition sessions. Overall adherence to this arm of the intervention was gauged by examining the percentage of participants who met the weight loss goal.

**2.4. Successful Aging (SA) Health Education Intervention.** Participants randomized into the PA+SA arm participated in a successful aging health education workshop series in addition to the PA program described above. The workshops were based on “The Ten Keys to Healthy Aging” [19], and the SA intervention used in the Lifestyle Interventions and Independence for Elders Pilot Study (LIFE –P) [17]. Topics included cholesterol, diabetes, blood pressure, bone and muscle health, smoking, cancer screening, social contact, depression, immunizations, and physical activity. Participants enrolled in this study arm attended 1 session per month, for a total of 12 sessions in addition to their physical activity sessions.

**2.5. Clinical Measurements.** At the baseline (BL) screening visit and followup visits, body height (cm) was measured using a wall-mounted stadiometer and body weight (kg) with a standard certified calibrated scale and were used to calculate BMI (weight (kg)/height (m<sup>2</sup>)). Waist circumference (cm) was also measured at BL and followup using the Gulick II Tape Measure (Country Technology Inc., Gray Mills, WI). Waist circumference was measured twice and rounded to the nearest 0.1 cm; if the two measurements had a difference greater than 5 cm, then a third measurement was obtained. The Short Physical Performance Battery (SPPB), a validated measure of lower extremity functional disability in older adults, was performed and included a 4 m walk, chair stands, and a balance test. More details concerning the SPPB can be found elsewhere [20]. Participants also completed questionnaires on sociodemographic data,

medical and hospitalization history, and the Community Healthy Activities Model Program for Seniors (CHAMPS) physical activity questionnaire [21]. The CHAMPS was used to quantify amount of physical activity as well as assess adherence to the PA program [22]. Activities performed at or above 3.0 metabolic equivalents (METs) were defined as moderate physical activity; the type of physical activity the program was designed to deliver. A resting ECG and a physical exam and interview with a nurse practitioner were conducted, before being medically cleared to participate in the physical activity intervention by the study physician.

**2.6. Dual Energy X-Ray Absorptiometry (DXA).** Total body fat mass, percent body fat, total lean body mass, appendicular lean body mass, total body bone mineral density (BMD), and total hip BMD were assessed using DXA (Hologic QDR 4500, software version 12.3; Bedford, MA). Bone mineral content was subtracted from the total and appendicular lean mass to define total nonbone lean mass, which represents primarily skeletal muscle in the extremities [23]. Appendicular lean mass was defined as the sum of upper and lower extremity lean mass [24].

**2.7. Computed Tomography (CT).** At BL and followup visits, axial CT scans (9800 Advantage, General Electric, Milwaukee, WI) were obtained and used to measure cross-sectional abdominal visceral and subcutaneous adipose tissue (VAT and SAT) areas using an established method [25]. Briefly, a cross-sectional scan at 10 mm thickness was obtained, centered at the L4-L5 vertebral disc space using 170 mA with a scanning time of two seconds and a 512 matrix. The visceral and subcutaneous AT boundary was defined using a manual cursor, and adipose tissue areas were determined using commercially available software (Slice-O-Matic, Tomovision, Montreal, Canada).

CT was also used to measure cross-sectional area (CSA) of mid-thigh muscle and adipose tissue and to characterize muscle attenuation. An anterior-posterior scout scan of the entire femur was used to localize the mid-thigh position. With the subject supine, a 10 mm cross-sectional scan of the dominant leg was obtained at the midpoint. The scanning parameters for this image were 120 kVp and 200–250 mA. This protocol has been utilized elsewhere [10].

Image analysis of adipose tissue and skeletal muscle CSAs of the thigh were calculated from the axial CT images using commercially available software (Slice-O-Matic, Tomovision, Montreal, Canada). Briefly, the mean attenuation coefficient values of muscle within the regions outlined on the images were determined by averaging the CT number (pixel intensity) in Hounsfield units (HU). The methodological variability of this measure is quite small [26]. Skeletal muscle and adipose tissue areas were calculated by the range of attenuation values for skeletal muscle (0 to 100 HU), normal density muscle (35–100 HU), and adipose (–190 to –30 HU) tissue. Intermuscular adipose tissue (IMAT) was distinguished from the subcutaneous (SUBQ) adipose tissue by manually drawing a line along the deep fascial plane surrounding the thigh muscles. Quadriceps muscles were separated from hamstring muscles with manual tracing.

Two additional reviewers analyzed thigh and abdominal scans from five randomly selected participants from this project and interrater reliability was assessed using a two-way mixed effects ANOVA model with SPSS 17.0 (SPSS Inc., Chicago, IL). The interclass correlation coefficient (ICC) was nonsignificant ( $P > .99$ ).

**2.8. Isokinetic Strength Testing.** At baseline and followup visits, isokinetic strength of the knee extensors was determined at 60°/s with a dynamometer (model 125 AP, Kin-Com, Chattanooga, TN). The right leg was tested unless it was injured or weaker by self-report or restricted in motion. After instruction on the procedure, the participant was positioned so that the lateral femoral epicondyle of the knee joint was aligned with the rotational axis of the dynamometer. The participant's leg was weighed for gravity correction, and start-stop angles were set at 90° and 30°. Two practice trials were performed at 50% effort to familiarize the participant with the procedure and to provide a warmup period. Each participant performed at least three maximal efforts. Beginning with the first maximal effort, the torque production over the entire range of motion was plotted, and the plot of each subsequent effort was overlaid on the previous efforts until three similar curves were obtained. Participants were not asked to perform more than six trials. Maximal torque production was recorded as the mean peak torque production from three similar trials. This methodology was used for the Health ABC Study [9]. Additionally, specific torque was calculated for each participant (knee extensor strength per unit area of the quadriceps) and used as a measure of muscle quality in the quadriceps.

**2.9. Statistical Analyses.** This paper focuses on BL and 6 month followup (6FU) data only. The changes in body composition and strength measures were determined by calculating the difference between the BL and 6FU values. The mean change for each body composition measure was calculated and then stratified by randomization assignment. Data were tested for normality. When normal, the Student's *t*-test was used to determine the significance of the differences in mean change between groups and a paired *t*-test was used to determine if the mean change within each group was significant from BL to 6FU. If the data were not normally distributed, the Wilcoxon Rank-Sum test was used to determine the significance of the differences in data distributions between randomization groups and the Wilcoxon Signed-Rank test was used to determine the significance of changes in data distributions within each group from BL to 6FU.

Correlation coefficients were used to quantify the relationships between the body composition measures and performance measures with Pearson coefficients used with normal variables and Spearman coefficients for nonnormal variables. The correlation coefficients and their associated *P*-values were used to determine if these relationships were significant.

Note that all values reported in tables are means and that a negative mean change denotes a decrease from BL to

6FU and a positive mean change denotes an increase from BL to 6FU. An alpha level of 0.05 was used as the threshold of significance. All analyses were performed using SAS 9.2 statistical software (SAS Institute, Inc.), except for the ICC described above.

### 3. Results

**3.1. Baseline.** Study participants ( $N = 36$ ) averaged  $70.3 \pm 5.9$  years of age, weighed, on average,  $87.9 \pm 8.9$  kg with a mean BMI of  $32.9 \pm 3.2$  kg/m<sup>2</sup>, classifying them as overweight to moderately obese at baseline [27]. All participants were nonsmokers. The population was 16.7% black and 16.7% male (Table 1). All participants, with the exception of one in the PA+SA group, were followed up to their 6FU visits. The participant dropped out of the study for personal reasons within the first phase of the intervention. SPPB data were missing for one participant at 6FU, in addition to the one dropout, due to an examiner error. Strength data is incomplete for three participants, in addition to the one dropout. One participant in the PA+SA group was unable to complete the test at both BL and 6FU due to bilateral knee replacement. Two participants, both in PA+WL are missing 6FU strength data due to examiner errors. Additionally, CT data were incomplete for four participants, in addition to the one dropout. In the PA+SA group, one participant had metal in their back and abdominal scans were unable to be obtained. Similarly, one person in this group had a hip replacement and all thigh measures. In the PA+WL group, one person was missing abdominal and one person was missing thigh scans due to metal deposits in the body.

There were no statistically significant differences between the PA+WL and PA+SA groups for baseline demographic, anthropometric, body composition, bone, strength, and functional characteristics, except for total SPPB score and total abdominal fat CSA (Tables 1 and 2) which were marginally significant. When total SPPB score was compartmentalized by component, there were no intergroup differences for any of the 3 component scores. Also, there were no significant differences at BL between intervention groups in self-reported PA levels as measured by the CHAMPS questionnaire ( $P = .17$ ).

**3.2. Intervention Efficacy and Adherence.** At 6FU, self-reported moderate PA increased uniformly in both intervention groups (by  $222.9 \pm 329.2$  min/week in PA+WL and  $199.0 \pm 319.1$  min/week in PA+SA), indicating an equally strong adherence to the PA program by both groups. In addition, 62% of the participants in the PA+WL group achieved 50% of their WL goal by 6 months (half of the intervention length), with 69% of these participants meeting or exceeding the weight loss goal. In addition, participants in the PA+WL group achieved, on average, a 5.5% weight reduction (79% of the 7% weight loss goal).

**3.3. Anthropometrics, Body Composition (DXA), and Bone Mass.** The PA+WL group decreased their mean waist

TABLE 1: Baseline demographic variables.

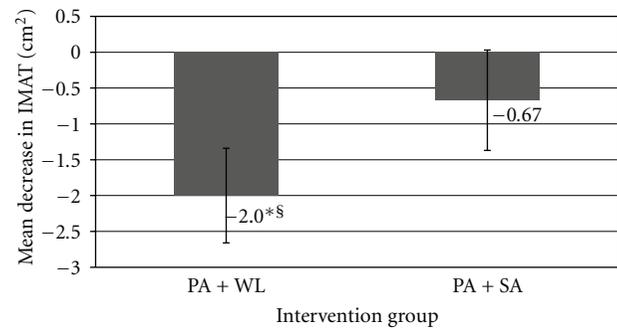
	Physical Activity + Weight Loss (N = 21)	Physical Activity + Successful Aging (N = 15)	P-value
	Mean change (BL-6FU)	Mean change (BL-6FU)	
Age (yrs)	70.6 (5.9) <sup>#</sup>	69.9 (5.9)	.80
Gender (%)			.68
Male	4 (19.0)	2 (13.3)	
Female	17 (81.0)	13 (86.7)	
Race (%)			.20
White	19 (90.5)	11 (73.3)	
African American	2 (9.5)	4 (26.7)	
Education (%)			.84
High school/GED	13 (65.0)	10 (66.7)	
College	6 (30.0)	2 (13.3)	
Other	1 (5.0)	3 (20.0)	
Household income (\$thousand/year) (%)			.99
< \$50 K	13 (61.9)	9 (60.0)	
> \$50 K	3 (14.3)	3 (20.0)	
Do not Know/Refused	5 (23.8)	3 (20.0)	

<sup>#</sup> ± Standard deviation.

circumference ( $-4.0 \pm 7.5$  cm,  $P = .03$ ), body weight ( $-4.9 \pm 4.8$  kg,  $P < .0001$ ) and BMI ( $-1.7 \pm 1.7$  kg/m<sup>2</sup>,  $P < .0001$ ) significantly from baseline to 6FU. The PA+SA group did not experience a significant mean change in any of these three measures (Table 3). The effects of weight loss in addition to regular PA were examined for several body composition measures using DXA (Table 3). The PA+WL group lost a significant amount of total body fat ( $-4.4 \pm 3.2$  kg,  $P < .0001$ ) whereas the PA+SA group did not ( $0.6 \pm 2.1$  kg,  $P = .27$ ). Participants' total body and total hip BMD were unchanged from BL to 6FU for both intervention groups (Table 3).

**3.4. Body Composition—CT.** The PA+WL group lost significant amounts of total abdominal fat ( $P < .01$ ), VAT ( $P < .01$ ) and SAT ( $P = .02$ ) from BL to 6FU, compared to no change in the PA+SA group ( $P = .8, .46$  and  $.84$ , resp.) (Table 3). The mean changes in total abdominal fat and VAT were both significantly different between intervention groups ( $P = .01$  and  $P < .01$ , resp.) (Table 3). The PA+WL group lost significant amounts of both total muscle ( $-2.3 \pm 3.9$  cm<sup>2</sup>,  $P = .03$ ) and adipose ( $-18.1 \pm 17.5$  cm<sup>2</sup>,  $P < .01$ ) tissue CSA, as well as IMAT ( $-2.0 \pm 2.9$  cm<sup>2</sup>,  $P < .01$ ) in the thigh. In comparison, the PA+SA group did not manifest significant decreases in any of these measures and actually gained some total thigh muscle CSA ( $1.5 \pm 3.4$  cm<sup>2</sup>,  $P = .13$ ). Mean change in total muscle CSA was the only one of these measures that differed significantly between intervention groups ( $P < .01$ ). Change in IMAT for both intervention groups is displayed in Figure 1.

The PA+WL group lost only  $2.2\% \pm 3.6$  of their baseline total muscle CSA as opposed to  $12.9\% \pm 10.7$  of their baseline total adipose CSA in the thigh. The discrepancy between total thigh fat and muscle loss is displayed in Figures 2 and 3. Despite the individual statistical significance of both these



\*Significant decrease from BL to 6FU ( $P < .05$ )

§No significant between group difference ( $P = .19$ )

Error bars denote standard error

FIGURE 1: Mean change in IMAT (cm<sup>2</sup>) from baseline to 6-month followup by intervention group.

changes, the participants in the PA+WL group lost a much greater proportion of their thigh adipose CSA as compared to thigh muscle CSA from BL to 6FU (Figures 2 and 3). When the quadriceps was isolated, the PA+WL group displayed significant decreases in total muscle CSA ( $-1.6 \pm 2.4$  cm<sup>2</sup>,  $P = .02$ ) whereas the PA+SA group did not ( $-1.4 \pm 3.9$  cm<sup>2</sup>,  $P = .31$ ).

The mean muscle attenuation values increased significantly in the PA+WL group ( $1.3 \pm 1.2$  HU,  $P < .01$ ) as well as in the PA+SA group ( $0.9 \pm 1.2$ ,  $P = .02$ ) (Table 3), indicating that participants' muscle tissue lipid content (fat infiltration) decreased in both intervention groups. Although the PA+WL groups' muscle tissue lipid content decreased to a greater degree than the PA+SA group, there was no significant difference in mean change in muscle fat-infiltration between groups ( $P = .32$ ). Similar patterns were observed when

TABLE 2: Baseline anthropometric, body composition, bone mass, muscle strength, and physical function by intervention group.

	Physical Activity + Weight Loss (N = 20) Mean change (BL-6FU)	Physical Activity + Successful Aging (N = 14) Mean change (BL-6FU)	P-value
<b>Anthropometric</b>			
Waist circumference, cm	108.8 (7.2) <sup>#</sup>	105.1 (8.8)	.22
Body weight, kg	89.8 (10.0)	85.4 (6.5)	.21
Height, cm	164.1 (8.4)	163.2 (5.2)	.77
BMI, kg/m <sup>2</sup>	33.6 (3.3)	32.1 (3.0)	.30
<b>DXA</b>			
Percent body fat	43.0 (5.4)	42.5 (6.1)	.73
Total fat mass, kg	38.0 (5.9)	35.9 (6.5)	.61
Total lean mass, kg	48.2 (7.6)	46.1 (5.2)	.55
Appendicular lean mass, kg	20.6 (3.7)	19.7 (2.8)	.47
Total body BMD, g/cm <sup>2</sup>	1.14 (0.12)	1.11 (0.15)	.53
Total hip BMD, g/cm <sup>2</sup>	0.93 (0.11)	0.93 (0.15)	.91
<b>Abdominal CT</b>			
Total, cm <sup>2</sup>	661.5 (134.1)	569.5 (97.6)	.04*
Visceral fat, cm <sup>2</sup>	217.7 (61.3)	179.8 (47.9)	.06
Subcutaneous fat, cm <sup>2</sup>	443.7 (124.5)	389.1 (93.4)	.17
<b>Right thigh CT</b>			
Total fat, cm <sup>2</sup>	150.8 (52.4)	137.9 (47.8)	.47
Subcutaneous, cm <sup>2</sup>	133.2 (52.8)	119.8 (47.4)	.45
Intermuscular fat, cm <sup>2</sup>	12.5 (3.6)	13.4 (5.5)	.57
Muscle mass (CSA), cm <sup>2</sup>	102.3 (23.2)	102.5 (90.2)	.99
Muscle density, HU	39.6 (3.1)	40.1 (3.3)	.62
Lean muscle mass, cm <sup>2</sup>	68.8 (18.9)	71.7 (21.1)	.64
<b>Right quadriceps CT</b>			
Muscle mass, cm <sup>2</sup>	49.2 (10.6)	50.1 (10.8)	.81
Muscle density, HU	44.2 (3.7)	44.6 (3.6)	.71
Lean muscle mass, cm <sup>2</sup>	37.7 (10.7)	39.6 (11.9)	.64
Specific torque (N·m/cm <sup>2</sup> )	2.2 (0.3)	2.2 (0.5)	.65
<b>Knee extensor strength</b>			
Peak torque, N·m	105.9 (32.2)	110.8 (23.7)	.66
Average torque, N·m	85.3 (25.2)	89.7 (24.6)	.62
<b>SPPB</b>			
Total	9.7 (1.4)	10.7 (1.1)	.05*
Chair stand score (0–4)	2.2 (1.1)	2.7 (1.0)	.15
Balance score (0–4)	3.7 (0.6)	4.0 (0)	.06
Gait speed score (0–4)	3.8 (0.5)	3.9 (0.3)	.48

<sup>#</sup> ± Standard deviation.

\*Significant at  $P < .05$ .

the quadriceps was isolated, with both groups showing significant decreases in fat-infiltration of the quadriceps (Table 3).

**3.5. Knee Extensor Strength.** The PA+WL group lost 12.4% ( $P = .01$ ) of peak isokinetic knee extensor strength from BL to 6FU; conversely, the PA+SA group did not (1%,  $P = .01$ ) (Table 3). However, these changes were not statistically significantly different between intervention groups ( $P = .11$ ) Similar patterns were observed for mean change in specific torque, the PA+WL group had a 11.1%  $N \cdot m \cdot cm^{-2}$  decrease

in mean specific torque compared to the  $<0.1\%$   $N \cdot m \cdot cm^{-2}$  decrease in the PA+SA group, but these were not statistically significant,  $P = .11$  and  $P = .99$ , respectively.

**3.6. Physical Function.** Both intervention groups uniformly improved physical function as measured by the SPPB. There were no intergroup differences in mean increase in SPPB score ( $P = .81$ ) (Table 3). However, the PA+WL group significantly improved their SPPB scores by  $0.70 \pm 1.42$ ,  $P = .04$  whereas the PA+SA group did not ( $0.50 \pm 0.94$ ,  $P = .13$ ).

TABLE 3: Mean changes in anthropometric, body composition, bone mass, muscle strength, and physical function measures from baseline to 6-month followup by intervention group.

	Physical Activity + Weight Loss (N = 19)		Physical Activity + Successful Aging (N = 13)	
	Mean change (BL-6FU)	P-value	Mean change (BL-6FU)	P-value
<b>Anthropometric</b>				
Waist circumference, cm	-4.0 (7.5) <sup>#</sup>	.03	-1.1 (5.2)	.50
Body weight, kg	-4.9 (4.8) <sup>§</sup>	<.001	-1.0 (3.5) <sup>§</sup>	.44
BMI, kg/m <sup>2</sup>	-1.7 (1.7) <sup>§</sup>	<.001	-0.4 (1.3) <sup>§</sup>	.46
<b>DXA</b>				
Percent body fat	-2.4 (1.9) <sup>§</sup>	<.001	-0.05 (1.3) <sup>§</sup>	.67
Total fat mass, kg	-4.4 (3.2) <sup>§</sup>	<.001	-0.6 (2.1) <sup>§</sup>	.27
Total lean mass, kg	-1.5 (1.7)	.001	-0.7 (1.4)	.08
Appendicular lean mass, kg	-0.9 (0.8)	.001	-0.5 (1.1)	.06
Total body BMD, g/cm <sup>2</sup>	-0.010 (.032)	.18	-0.006 (.026)	.41
Total hip BMD, g/cm <sup>2</sup>	-0.002 (.032)	.72	0.005 (.014)	.17
<b>Abdominal CT</b>				
Total fat, cm <sup>2</sup>	-75.1 (94.4) <sup>§</sup>	<.01	-5.2 (72.4) <sup>§</sup>	.80
Visceral fat, cm <sup>2</sup>	-38.1 (40.4) <sup>§</sup>	<.01	-5.5 (26.2) <sup>§</sup>	.46
Subcutaneous fat, cm <sup>2</sup>	-37.0 (62.8)	.02	-0.4 (55.9)	.84
<b>Right thigh CT</b>				
Total fat, cm <sup>2</sup>	-18.1 (17.5)	<.01	-5.4 (9.9)	.07
Subcutaneous, cm <sup>2</sup>	-15.4 (14.8)	<.01	-4.8 (9.5)	.09
Muscle mass, cm <sup>2</sup>	-2.3 (4.0) <sup>§</sup>	.03	1.5 (3.7) <sup>§</sup>	.13
Muscle density, HU	1.3 (1.2)	<.01	0.9 (1.2)	.02
Lean muscle mass, cm <sup>2</sup>	1.7 (4.0)	.08	2.8 (4.2)	.04
<b>Right quadriceps CT</b>				
Muscle mass, cm <sup>2</sup>	-1.6 (2.4)	.02	-1.4 (3.9)	.31
Muscle density, HU	1.3 (3.7)	<.01	1.0 (1.4)	.03
Lean muscle mass, cm <sup>2</sup>	-0.17 (2.2)	.54	-0.41 (3.5)	.79
Specific torque, N·m/cm <sup>2</sup>	-0.24 (0.58)	.11	-0.001 (0.31)	.99
<b>Knee extensor strength</b>				
Peak torque, N·m	-16.8 (27.9)	.01	-2.5 (17.2)	.91
Average torque, N·m	-14.0 (22.0)	.01	-3.3 (13.5)	.45
SPPB score	0.7 (1.4)	.04	0.5 (0.9)	.13

<sup>#</sup> ± Standard deviation.

<sup>§</sup> Denotes a significant difference between intervention programs,  $P < .05$ .

TABLE 4: Correlations between change in body composition measures with change in muscle strength and physical function.

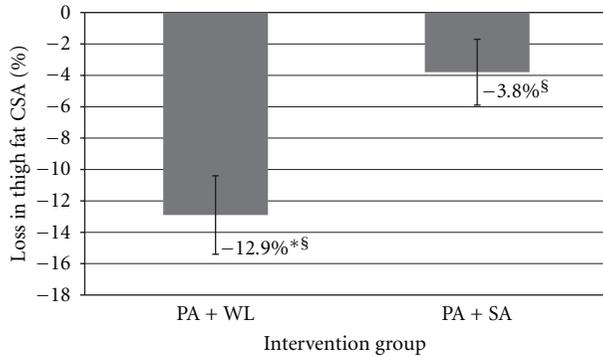
	Total abdominal fat	SAT-abdominal	VAT-abdominal	Thigh fat CSA	Thigh muscle CSA	Thigh muscle density	Thigh IMAT
Total SPPB	-0.47 <sup>§</sup>	-0.38*	-0.53 <sup>§</sup>	-0.34	-.003	-0.08	-0.41*
Chair stand component	-0.44*	-0.42*	-0.36*	-0.28	-0.07	0.09	-0.39*
Peak torque	0.14	0.12	0.23	0.10	0.05	-0.27	0.02

\* Significant at  $P < .05$  level.

<sup>§</sup> Significant at  $P < .01$  level.

**3.7. Relationship between Body Composition and Strength with Physical Function.** Changes in fat tissue were more closely related to change in total and chair stand component of the SPPB score than were changes in muscle tissue and strength. The mean change in chair stand and total SPPB score were

strongly inversely correlated ( $P < .05$ ) with mean change in total visceral and subcutaneous abdominal fat as well as intermuscular adipose tissue in the thigh (Table 4). Total SPPB, chair stands SPPB score and strength was not strongly correlated with mean change in any of the lean tissue or

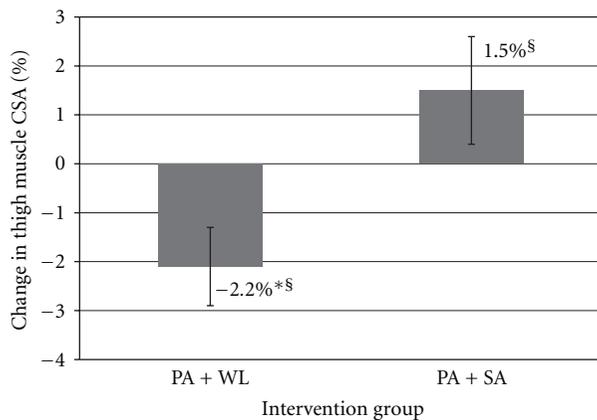


\*Significant change from BL to 6FU ( $P < .05$ )

§Significant between group difference ( $P = .02$ )

Error bars denote standard error

FIGURE 2: Percent change in total thigh fat CSA from Baseline to 6-month followup by intervention group.



\*Significant decrease from BL to 6FU ( $P < .01$ )

§Significant between group difference ( $P < .01$ )

Error bars denote standard error

FIGURE 3: Percent change in total thigh muscle CSA from baseline to 6-month followup by intervention group.

muscle quality measures. In addition, mean change in total fat CSA in the thigh was much more closely related to change in chair stand and total SPPB score than total thigh muscle CSA (Table 4).

#### 4. Discussion

The primary focus of this study was to assess the added effects of weight loss and PA on physical function in older adults and the extent to which changes might be mediated by muscle mass, muscle fat infiltration, and muscle strength. The PA+WL group lost a significant amount of both total muscle and fat CSA from BL to 6FU, as compared to the PA+SA group, which did not manifest significant changes in these measures. These results are similar to those in previous studies, as it has been shown that weight loss induces a loss

of lean mass in older adults. In other studies with a weight loss only comparison group, a regular PA program consisting of walking, resistance, and balance training attenuated age-related loss of muscle mass [10, 28].

As anticipated, the PA+WL group significantly decreased the lipid content of their muscle tissue, as measured by muscle attenuation, but this increase was not enough to attenuate the effects of the decreases in muscle mass on strength, as the PA+WL group lost a significant amount of strength from BL to 6FU. This finding is contradictory to a similar study, conducted by Wang et al., comparing the effects of WL and PA to a true control group on strength and body composition, which reported an 8% increase in eccentric knee strength [15]. Participants in that study were diagnosed with osteoarthritis in the knee, so it is possible that the benefits of WL and regular PA were accentuated in this population. These differing results could also be a result of key differences in the WL interventions. The WL intervention in the Wang et al. study provided meal replacement shakes and bars for two meals and a menu plan with recipes for the third. The investigators did this to better control the percentage of caloric intake from protein, fat, and carbohydrates. The WL intervention in this study was not as strict, simply concentrating on a low-fat, low-calorie healthy eating pattern. These differences are important because protein intake has been shown to affect muscle protein synthesis and, in turn, muscle mass in older adults [29]. Perhaps WL and PA randomized controlled trials conducted in older adults should include a higher protein intake.

The PA+SA group lost some nominal muscle strength. A loss of strength is expected with aging, so that this may represent an attenuation of this expected loss. Indeed, this concurs with the results a previous study of the LIFE-P Study, which demonstrated that a regular, moderate intensity PA program can attenuate the loss strength in older adults [10]. When mean change in knee extensor strength was compared between groups, there was a trend towards statistical significance ( $P = .11$ ); which suggests that intentional weight loss with regular PA accelerates the loss of strength with age, as compared to regular PA alone. The results of this study also differed from the study by Wang et al. [15] in respect to muscle quality. In this study, those in the PA+WL group decreased their muscle quality (suggestive but not statistically significant,  $P = .11$ ), compared to the participants in their study who significantly increased their muscle quality [15]. This may be due to the fact that muscle quality was calculated differently in this study and for the differences in the two WL interventions described above. The PA+SA group experienced virtually no change in muscle quality from BL to 6FU, a result consistent with LIFE-P [10].

The PA+WL group improved function to a greater degree than the PA+SA group despite losing significant amounts of both lean mass and strength. This is because participants in this group lost 6-fold more fat mass than lean mass in the thigh, which resulted in a more optimal lean mass to fat mass ratio and were probably better able to carry their weight. These results suggest that the loss of fat is important in improving function in generally healthy, overweight to

moderately obese adults over the age of 60. The strong correlations between mean change in chair stands and total SPPB scores with mean change in total visceral and subcutaneous abdominal fat as well as intermuscular adipose tissue in the thigh suggest that this improvement in function was due to losses in adipose tissue rather than gains or attenuation of losses in muscle mass. These findings seem to suggest that older adults can improve function while losing both fat and muscle mass, as long as the individual loses a significantly greater proportion of fat mass compared to muscle mass. This finding is consistent with previous studies assessing the effects of WL with regular PA in older adults with knee osteoarthritis [30–32]. It is worth noting that this intervention trial is still ongoing so it is possible that these may only be short-term effects. It will be important to observe any further changes in body composition and function that take place during the longer followup period.

Participants in the PA+WL group lost a significant amount of both visceral (17.5%) and thigh (11.6%) subcutaneous (i.e., gluteofemoral) fat. The latter has been shown to possess certain protective properties including independent associations with lower total and low-density lipoprotein cholesterol as well as vascular health benefits, such as decreased aortic calcification and arterial stiffness [33–37]. Participants in this study were in the overweight to moderately obese BMI categories upon enrollment and the functional benefit was clear. However, weight loss interventions involving older adults should evaluate relative effects of changes in fat distribution on metabolic function.

This study has several strengths. Both interventions were shown to be effective, as shown by outstanding efficacy and adherence, and functional outcomes were used to measure physical function rather than self-reported function. This eliminates any potential recall bias. Also, that there were limited physical functioning exclusion and inclusion criteria; meaning the results of this study are generalizable to both low and high physically functioning older adults. However, future studies could be designed to recruit a higher number of lower functioning people, as this population was fairly high functioning at baseline. One limitation of this study is that it lacks other control groups, which would consist of participants receiving either a WL intervention or health education program, making it difficult to distinguish the effect of weight loss alone from the activity intervention [10]. Additionally, the participants were fairly healthy, thus the findings may not be relevant to more frail older adults.

In conclusion, a physical activity plus weight loss intervention program significantly improved function and decreased both fat and muscle CSA, compared to PA plus successful aging health education in generally healthy, overweight to moderately obese adults over the age of 60. While, PA+WL resulted in significant decreases in knee extensor strength compared with PA+SA in this population, this did not translate into functional decline. This study also demonstrated that PA+WL conferred a 6-fold decrease in thigh fat mass compared to lean mass and that this more optimal lean mass to fat mass ratio resulted in improved physical function. The obesity epidemic is affecting all age groups and could decrease prospects for an active life

expectancy in older adults. The potential to improve mobility and decrease disability in older adults is substantial. These findings provide important novel insight into the risks, benefits and mechanisms of weight loss in overweight to moderately obese older adults.

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## Research Article

# Predictors of Psychological Well-Being during Behavioral Obesity Treatment in Women

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This study examined the association of autonomy-related variables, including exercise motivation, with psychological well-being and quality of life, during obesity treatment. Middle-aged overweight/obese women ( $n = 239$ ) participated in a 1-year behavioral program and completed questionnaires measuring need support, general self-determination, and exercise and treatment motivation. General and obesity-specific health-related quality of life (HRQOL), self-esteem, depression, and anxiety were also assessed. Results showed positive correlations of self-determination and perceived need support with HRQOL and self-esteem, and negative associations with depression and anxiety ( $P < .001$ ). Treatment autonomous motivation correlated positively with physical ( $P = .004$ ) and weight-related HRQOL ( $P < .001$ ), and negatively with depression ( $P = .025$ ) and anxiety ( $P = .001$ ). Exercise autonomous motivation was positively correlated with physical HRQOL ( $P < .001$ ), mental HRQOL ( $P = .003$ ), weight-related HRQOL ( $P < .001$ ), and self-esteem ( $P = .003$ ), and negatively with anxiety ( $P = .016$ ). Findings confirm that self-determination theory's predictions apply to this population and setting, showing that self-determination, perceived need support, and autonomous self-regulation positively predict HRQOL and psychological well-being.

## 1. Introduction

Self-determination theory is a well-known psychological framework to study people's behavior, based on the assumption that humans are innately motivated toward growth and health, a process which can be nurtured or thwarted by the social environment [1, 2]. Much research on self-determination theory, particularly in the health domain, has focused on the study of the characteristics of motivation and associated regulatory processes. For instance, the degree to which people feel autonomous (i.e., self-determined) versus controlled in their motivated pursuits, and how this relates to behavioral persistence (e.g., [3, 4]). Intrinsic motivation, the doing of an activity for its inherent satisfactions, is highly autonomous and represents the prototypic instance of self-determination, while extrinsically motivated behaviors, by contrast, cover the continuum between amotivation and intrinsic motivation, varying in the extent to which their regulation is autonomous. Within extrinsic regulations,

autonomous regulations (identified and integrated) reflect a sense of personal volition and recognition of the importance of the target behavior and its consequences. In contrast, in controlled regulations (external and introjected) people feel forced to comply with outside demands or feel guilty or ashamed if they do not perform the target behavior [1, 2].

The concept of basic needs is central for self-determination theory. It states that people have innate psychological needs that when fulfilled have an effect on personal growth, psychosocial adjustment, feelings of integrity, and well-being [5]. Additionally, it clarifies the relationships between the satisfaction of the needs for competence, autonomy, and relatedness and psychological functioning and well-being. It should be noted that, from a self-determination theory perspective, well-being is not concerned exclusively with "hedonic" or subjective well-being in the tradition of Positive Psychology [6], namely, the experience of happiness, usually characterized by high positive affect, reduced negative affect, and life satisfaction

[7]. Self-determination theory favors a “eudaimonic” view of well-being, focused on feeling fully functioning, self-coherent, and with a deep sense of wellness, and vitality [8], rooted on the idea of fulfilling or realizing one’s *daimon* or true nature [9]. As a consequence of this broader notion of well-being, which includes happiness and emotional well-being but also meaning and personal growth, psychological well-being has been assessed in self-determination theory studies with indicators of positive affect and mental health. Some examples are self-esteem, vitality, life satisfaction, and also (low levels of) depression and anxiety [10, 11].

Previous studies in exercise contexts which examined perceived choice, a marker of autonomy, in relation to well-being found that it was associated with reduced negative affect [12] and positive well-being [13]. More recent studies in the exercise domain showed that the satisfaction of basic psychological needs for competence, autonomy, and relatedness enhanced psychological well-being in the form of physical self-perception [14], subjective vitality and positive affect [10, 11], enjoyment and intrinsic motivation for exercise [15], and satisfaction with life [11].

Numerous studies have demonstrated that obese individuals experience significant impairments in health-related quality of life (HRQOL) as a result of their weight, with greater impairments being associated with greater degrees of obesity [16–18]. Conversely, weight loss has been shown to improve quality of life in obese persons undergoing a variety of treatments [16]. Assessing quality of life is especially important to help determine the comparative efficacy of different treatments and to assess the impact of treatment on how patients feel and function in their everyday life [19, 20]. The use of both general and specific quality of life instruments is a methodological recommendation from previous obesity HRQOL research [21].

HRQOL, as measured by the SF-36, improves after small to moderate amounts of weight loss with nonsurgical methods [16]. Not only weight loss [22] but also weight maintenance is considered to be beneficial for physical HRQOL [23]. Using obesity-specific measures, such as the IWQOL and IWQOL-Lite, quality of life improvements were associated with decrease in body weight in different studies [22, 24–26]. In a recent meta-analysis, weight loss treatment was associated with lowered depression and increased self-esteem [27]; only treatments that produced actual weight loss predicted increased self-esteem, whereas improvements in depression were independent of weight loss.

In Portugal, the prevalence of overweight and obesity is 53.6% in adult women; of these 13.4% are obese and 34.4% are overweight [28]. However, there are very few studies that have analyzed markers of quality of life and well-being among the Portuguese population, particularly in overweight or obese individuals. One study showed that body image and physical dimensions of obesity-specific quality of life improved significantly during the course of treatment [29]. Another study indicated that changes in weight and body image may reciprocally affect each other during the course of behavioral obesity treatment, and that weight loss partially mediated the effect of treatment on quality of life and on self-esteem [30].

In the present study, our goal was to assess the association of perceived need support, general self-determination (as measured by perceived choice), and treatment and exercise motivation (autonomous versus controlled regulation) with variables reflecting psychological well-being and quality of life, during a behavioral obesity treatment program lasting 1 year. Based on self-determination theory, we predicted that higher perceived need support, higher self-determination, and more autonomous treatment and exercise self-regulation would be associated with higher HRQOL and improved psychological well-being. To our knowledge, only a few studies have examined predictors of psychological well-being in overweight/obese persons during behavioral treatment [29, 30] and none have tested self-determination theory variables as putative predictors.

## 2. Materials and Methods

**2.1. Design.** The study was conducted within a randomized controlled trial in overweight and moderately obese women, primarily focused on increasing exercise self-motivation and exercise adherence, aiming at long-term weight control. The intervention group participated in weekly or bimonthly sessions during approximately one year. The program’s principles and intervention style were based on self-determination theory, while the control group received a general health education program. The intervention and its theoretical rationale have been described in detail elsewhere [31, 32]. The Faculty of Human Kinetics Ethics Committee reviewed and approved the study.

**2.2. Participants.** Participants ( $n = 239$ ,  $37.6 \pm 7.1$  years old;  $BMI = 31.5 \pm 4.1$   $kg/m^2$ ) were recruited from the community at large through media advertisements. About 67% of the study participants had at least some college education, 23% had between 10 and 12 years of school and 10% had 9 years or less of school. At baseline, women in the intervention group did not differ from those in the control group in terms of BMI, age, education, or marital status [31]. There were also no differences between the 208 women who completed the 12-month intervention and the 31 who withdrew from the program, for any demographic or baseline psychosocial variable, with the exception of age; women who stayed in the program were on average four years older ( $P = .01$ ).

**2.3. Measurements.** Data was collected at baseline, corresponding to the pretreatment scores, and at 12 months, corresponding to the end of the treatment. The instruments were validated Portuguese versions of some of the most commonly used psychosocial instruments in obesity research and are described in detail below.

**2.3.1. Self-Determination Measures.** Self-determination was assessed with the Perceived Choice subscale from the Self-Determination Scale [33], an instrument designed to evaluate individual differences in the extent to which people function in a self-determined way (e.g., “I do what I do because it interests me”, “I do what I do because I have to”,

“What I do is often not what I’d choose to do”). Cronbach’s  $\alpha$  was 0.83. Participants’ perceived need support was evaluated with the Health Care Climate Questionnaire [3]. It includes items reflecting fostering of autonomy (e.g., “I feel that the staff has provided me choices and options”), involvement (e.g., “The staff handles peoples’ emotions very well”), and the provision of structure (e.g., “the staff has made sure I really understand my condition and what I need to do”). Total score is calculated by summing response items, higher scores indicating higher perceptions of need support climate (Cronbach’s  $\alpha = 0.96$ ).

Self-regulation for treatment was measured with the Treatment Self-Regulation Questionnaire [3] assessing the degree to which a person’s motivation for participating in treatment is autonomous versus controlled. Items are summed into two subscales, one measuring autonomous (Cronbach’s  $\alpha = 0.86$ ), the other controlled (Cronbach’s  $\alpha = 0.80$ ) regulation. Exercise regulations were assessed by the Self-Regulation Questionnaire for Exercise [34] measuring exercise regulatory motives. The scale can also be summarized into two subscales, autonomous (Cronbach’s  $\alpha = 0.91$ ) and controlled exercise regulation (Cronbach’s  $\alpha = 0.73$ ).

**2.3.2. Health-Related Quality of Life Measures.** General quality of life was measured with the SF-36 [35, 36], composed of two scales and a total of 36 items, reflecting physical (physical component summary, PCS) and psychological (mental component summary, MCS) composite values (Cronbach’s  $\alpha$  between 0.66 to 0.87), in which higher results represent greater quality of life perception. The weight-related aspects of health-related quality of life was assessed using the Impact of Weight on Quality of Life – Lite scale (IWQOL-L) [37, 38], a 31-item questionnaire (Cronbach’s  $\alpha = 0.93$ ). Higher scores indicate higher weight-related quality of life.

**2.3.3. Psychological Well-Being Measures.** Self-esteem was assessed with the Rosenberg Self-Concept/Self-Esteem Scale [39, 40] with higher scores of the RSES representing greater self-esteem (Cronbach’s  $\alpha = 0.88$ ). Depression was evaluated with the Beck Depression Inventory [41, 42], where higher scores represent greater levels of depressive symptoms (Cronbach’s  $\alpha = 0.87$ ). State anxiety was assessed with the State-Trait Anxiety Inventory [43], where higher scores represent greater levels of anxiety (Cronbach’s  $\alpha = 0.92$ ).

**2.3.4. Body Weight.** Body weight was measured twice with a standardized procedure (average was used) at baseline and at the end of the treatment (12 months) using an electronic scale (SECA model 770, Hamburg, Germany). Height was measured with a balance-mounted stadiometer to the nearest 0.1 cm.

**2.4. Statistical Procedures.** For quality of life and psychological well-being variables, 12-month standardized residuals were used, calculated by regressing the 12-month value onto the baseline value, producing an outcome variable which is entirely orthogonal to (i.e., adjusted for) the baseline

value [44]. Unadjusted 12-month scores were used for treatment and exercise motivation, perceived need support, and self-determination. This option was based on the fact that most participants did not engage in regular exercise at the beginning of the intervention, which yielded exercise self-regulation measures less valid (e.g., “I exercise because I”...). Also, treatment self-regulation (i.e., reasons to *stay* in treatment) and perceived need support from the intervention team could only be evaluated after participants started the intervention. For consistency, the same procedure was adopted for general self-determination.

Statistical analyses were completed using the Statistical Package for the Social Sciences (PASW Statistics 18). Pearson correlations and partial correlations were used to test associations among all variables in the study, and also to examine associations between the independent variables and a global well-being z-score, computed as mean value of all HRQOL and psychological well-being z-scores, before and after adjusting for group. Stepwise linear regressions were used to analyze the independent effect of self-determination theory’s factors on HRQOL and psychological well-being. We ran the same analysis controlling separately for a potential intervention effect and for an effect of weight change on outcomes. Tertiles were computed based on the mean z-score value to define success groups. Mean differences in HRQOL and psychological well-being between women in the “low HRQOL and psychological well-being” and “high HRQOL and psychological well-being” tertile-formed groups were tested using independent *t*-tests. Type I error was set at  $\alpha = 0.05$  (two-tailed) for all tests.

### 3. Results

At the end of the 12-month intervention, there was an overall 87% retention rate. Correlations among independent variables and measures of well-being are presented in Table 1. Self-determination ( $P = .001$ ), perceived need support ( $P < .001$ ), treatment autonomous self-regulation ( $P < .001$ ), and exercise autonomous self-regulation ( $P < .001$ ) were positively associated with the global well-being z-score, while treatment controlled self-regulation was negatively correlated with well-being ( $P = .001$ ). Similar results were found after adjusting for group. More specifically, self-determination correlated positively with HRQOL and self-esteem, and negatively with depression and anxiety. Regarding self-determination theory treatment variables, perceived need support was positively correlated with physical, mental, and weight-related HRQOL, and with self-esteem; in turn, correlations were negative with depression and anxiety. Treatment autonomous self-regulation was positively associated with physical and weight-related HRQOL, negatively with depression and anxiety, and not related to mental HRQOL. Conversely, treatment controlled self-regulation correlated positively with anxiety and negatively with self-esteem, physical, and weight-related HRQOL. For exercise variables, results indicated that autonomous self-regulation was positively associated with HRQOL and self-esteem, but negatively correlated with anxiety. Controlled

TABLE 1: Self-determination theory variables correlation with HRQOL and psychological well-being (at 12 months).

	PCS HRQOL	MCS HRQOL	Obesity specific HRQOL	Self-Esteem	Depression	Anxiety	z-score well-being	
	<i>r</i>	<i>r</i>	<i>r</i>	<i>r</i>	<i>r</i>	<i>r</i>	<i>r</i>	<i>r</i> partial
Self-determination	0.27***	0.33***	0.18*	0.27***	-0.16*	-0.33***	0.37***	0.36***
Perceived need support	0.19**	0.15*	0.29***	0.15*	-0.16*	-0.25**	0.28***	0.20**
Treatment controlled self-regulation	-0.14*	-0.09	-0.26***	-0.14*	0.11	0.28***	-0.23**	-0.27***
Treatment autonomous self-regulation	0.20**	0.12	0.26***	0.12	-0.17*	-0.24**	0.27***	0.16*
Exercise controlled self-regulation	0.01	-0.01	-0.07	-0.12	0.08	0.09	-0.06	-0.11
Exercise autonomous self-regulation	0.28***	0.21**	0.27***	0.15*	-0.11	-0.17*	0.30***	0.23**

*r*: Person's correlation coefficient; \* $P < .05$ , \*\* $P < .05$ , \*\*\* $P < .001$ ; *r* partial: partial correlation coefficient adjusting for group; PCS: physical component summary; MCS: mental component summary; z-score was computed as mean value of all HRQOL and psychological well-being z-scores.

TABLE 2: Multiple regression for psychological well-being z-score at intervention's end.

	<i>B</i>	SE <i>B</i>	$\beta$	Adj $R^2$	<i>P</i>
Model 1					
Self-determination	0.04	0.010	.25***		
Perceived need support	0.01	0.003	.16*		
Treatment controlled self-regulation	-0.02	0.005	-.22**		
Exercise autonomous self-regulation	0.01	0.006	.18*	0.24	<.001
Model 2					
Group	0.11	0.048	.16*		
Self-determination	0.04	0.010	.28***		
Perceived need support	0.01	0.003	.17*		
Treatment controlled self-regulation	-0.02	0.005	-.22**	0.24	<.001
Model 3					
Weight change	-0.14	0.043	-.22**		
Self-determination	0.04	0.010	.28***		
Perceived need support	0.01	0.003	.22**		
Treatment controlled self-regulation	-0.02	0.005	-.20**	0.28	<.001

z-score was computed as mean value of all HRQOL and psychological well-being z-scores; group was coded as 1 to the intervention group, -1 to the control group; note that a negative weight change represents weight loss (a positive outcome); \* $P < .05$ ; \*\* $P < .01$ ; \*\*\* $P < .001$ .

exercise self-regulation was generally not associated with psychological outcomes.

Next, we ran multiple regression models, using self-determination, perceived need support, treatment self-regulation, and exercise self-regulation as independent variables and global well-being as the dependent variable. Results are presented in Table 2. Self-determination, perceived need support, controlled treatment self-regulation (negative association), and exercise autonomous self-regulation were independent predictors of global psychological well-being and explained 29% of the variance. To test whether these relations held when adjusting for group (i.e., controlling for the intervention effect), the same regression model was run, this time with group assignment forced into the model. Results

were comparable to the unadjusted model (28% variance explained,  $P < .001$ ); however, only self-determination, controlled treatment self-regulation (negatively), and perceived need support were found to predict psychological well-being (see Model 2 in Table 2). To test if weight change was a confounding factor in these relations, the same regression model was run with weight change also in the model (see Model 3 in Table 2). Results were comparable to Model 2 (33% variance explained;  $P < .001$ ).

A final analysis was conducted, comparing z-scored self-determination theory variables at the highest and lowest of tertiles of global well-being (z-scored) (see Figure 1). Participants in the higher psychological well-being group had higher self-determination ( $P < .001$ ), perceived need

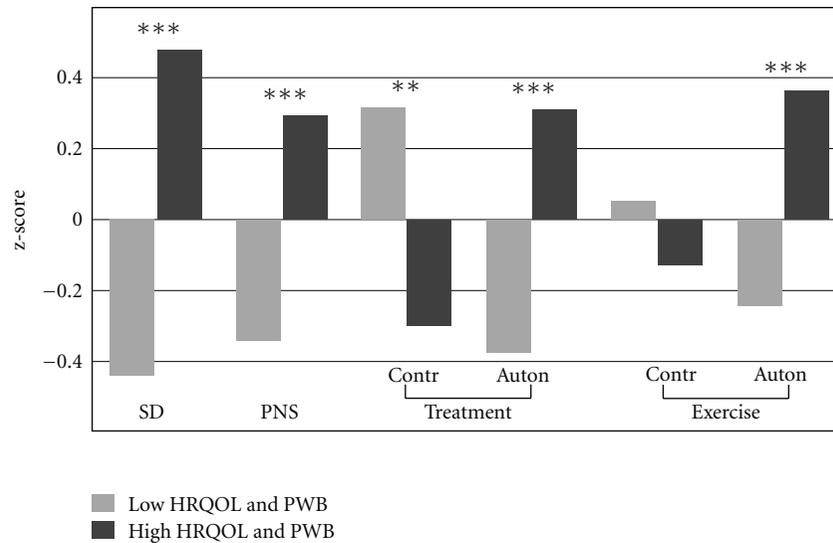


FIGURE 1: *Self-determination theory-based variables by tertile-split group of HRQOL and psychological well-being (at 12 months)*. HRQOL: health-related quality of life; PWB: psychological well-being; SD: self-determination; PNS: perceived need support; Contr: controlled; Auton: autonomous; *P*: *P* values for independent *t*-test comparing two tertiles considering global HRQOL and PWB z-score, tertile 1 defined as unsuccessful (low) HRQOL and PWB group and tertile 3 defined as successful (high) HRQOL and PWB group; \*\**P* < .01; \*\*\**P* < .001.

support ( $P < .001$ ), lower treatment controlled self-regulation ( $P = .001$ ), higher treatment autonomous self-regulation ( $P < .001$ ), and higher exercise autonomous self-regulation ( $P < .001$ ). The groups did not differ for exercise controlled self-regulation.

#### 4. Discussion

The primary goal of this study was to examine the association of general, contextual (obesity treatment), and situation-specific (exercise-related) measures of self-determination with psychological well-being and HRQOL. To briefly summarize our findings, higher self-determination and perceived need support, lower treatment controlled self-regulation, and higher exercise autonomous self-regulation were significant predictors of well-being in the course of a 1-year behavioral treatment for obesity, before and after adjustment for weight change.

According to self-determination theory, more self-determined behavior, which is partially derived from need-supportive interactions with one's environment, leads to improved psychological well-being [45]. This causal path is supported by the present results, the first of this kind to be conducted in the context of behavioral obesity treatment. Additionally, participants in this study who indicated more autonomous reasons to participate in treatment also reported higher scores on most markers of psychological well-being. Finally, women with higher HRQOL and enhanced psychological well-being were those for whom exercise behavior was associated with valued outcomes and/or for whom being physically active was enjoyable and optimally challenging (autonomous regulation). We have previously detailed the mechanisms by which interventions can promote autonomous self-regulation for treatment and specifically for exercise [31, 32].

In an exercise-specific context, a study by Wilson et al. showed that if the needs for competence, autonomy, and relatedness in an exercise setting are satisfied, subjective vitality and the degree of positive affect typically experienced within one's exercise session are enhanced [10]. In overweight sedentary women, externally imposed exercise intensity led to a significant decline in ratings of pleasure during exercise session, compared to self-selected intensity [15]. These findings have bearing on the importance of perceived choice in exercising, which could exert positive effects on autonomous regulation, intrinsic motivation, and adherence [15]. Another study with overweight and obese individuals, using positive and negative affect, subjective vitality, and satisfaction with life as measures of well-being, showed that exercise-related autonomy positively predicted satisfaction with life and that intrinsic motivation was a positive predictor of positive affect, while introjected regulation was found to be a negative predictor of subjective vitality [11]. In fact, research generally indicates that more autonomous regulations enhance not only behavioral persistence but also psychological well-being [3, 46, 47]. In contrast, controlled regulations are typically associated with diminished psychological well-being, also reflected in lower self-esteem [48]. Results of the present work are consistent with these findings in showing that treatment and exercise autonomous self-regulation also predict better psychological well-being in overweight or obese women undergoing treatment.

In the present study, as predicted, controlled reasons to stay in treatment predicted poorer psychological well-being. However, controlled motivation towards exercise was generally not related to psychological outcomes. As assessed in this study, controlled regulations include reasons with a clear external frame of reference (e.g., "I exercise because I want others to see me as physically fit", "I exercise because

I want others to see me as physically fit”) and reasons which have been introjected or partially internalized (e.g., “I exercise because I’d be afraid of falling too far out of shape”, “I exercise because I would feel bad about myself if I did not do it”). One interpretation for the present findings is that external demands and pressures to exercise in this study were perceived by participants as coming mostly from the intervention team. To the extent that this occurred, external contingencies and incentives, which normally could have been felt as controlling and a potential cause of anxiety, may have been perceived as normal, expected, and even positive by some participants. This was likely the case in the main intervention group, for whom introjected, integrated, and intrinsic exercise motivation were found to increase (compared to controls) at the end of an intervention which was overwhelmingly perceived as supporting participants’ autonomy [31]. In fact, group differences in the psychological impact of introjected and/or external regulations may partially explain the generally nonsignificant results.

According to self-determination theory, satisfaction of competence, autonomy, and relatedness, the three basic psychological needs, provide a basis for predicting when the pursuit and attainment of goals will be associated with more positive versus more negative well-being outcomes [45]. In contrast, thwarted satisfaction of these needs results in negative functional consequences for mental health. Persistent deprivation of any need has costs for health and well-being, leading to the development of compensatory processes, such as substitute motives and non-autonomous regulatory styles, which are expected to result in worse well-being. Thus, need thwarting conditions lead to specifiable patterns of behaviors, regulations, goals, and affects that do not represent optimal development and well-being, which would occur in supportive environments [45]. Our findings suggest that, in the context of weight loss treatment, perceived need support and autonomous self-regulation will also lead to increased HRQOL and improved psychological well-being.

Several studies showed that weight loss is important in overweight and obese populations in part due to beneficial effects on HRQOL and psychological well-being. For example, Kolotkin and colleagues found that obesity-specific HRQOL changes were strongly related to weight reduction among 161 participants (88% women) [49]. Additionally, improved mood, affect, and psychological well-being may also facilitate the adoption and maintenance of behavior needed to regulate one’s weight [30]. Thus, improving psychological well-being is not only ethically appropriate but could also be good clinical practice, to the extent that it contributes to enhanced treatment outcomes. Unfortunately, investigating predictors of psychological well-being in obesity treatment has not been the focus of much prior research. An additional ethical medical mandate is to promote patients’ autonomy [50]. Interestingly, an increasing body of research shows that promoting autonomy is also advisable from a treatment efficacy viewpoint. For example, in weight loss and weight maintenance, more autonomous and intrinsic motivation have been shown to significantly predict more successful weight and exercise-related outcomes [3, 51–53].

In conclusion, this work supports predictions based on self-determination theory in relation to correlates of quality of life and psychological functioning. For obesity treatment, this study furthers our understanding of mechanisms associated with enhanced psychological outcomes, which is of direct relevance for health care providers in this field. Promoting self-determined motivation for health and health behaviors, particularly exercise, may positively influence a number of relevant psychological variables. Importantly, during weight control, these associations appear to hold independently of actual weight changes.

## Acknowledgments

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## Research Article

# Behavioral and Psychological Factors Associated with 12-Month Weight Change in a Physical Activity Trial

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Examining behavioral and psychological factors relating to weight stability over a 1-year period is of public health importance. We conducted a physical activity (PA) intervention trial for women ( $N = 247$ ; mean age =  $47.5 \pm 10.7$ ; mean BMI =  $28.6 \pm 5.3$ ) in which participants were assigned to one of three groups (two PA and one contact-control). By Month 12, participants achieved  $140.4 \pm 14.82$  min of PA/week, with no group differences. Weight status change from baseline to Month 12 was categorized: *no change* ( $N = 154$ ; 62.4%); *increase* ( $N = 34$ ; 13.8%); *decrease* ( $N = 59$ ; 23.9%). Discriminant function analyses identified two statistically significant dimensions associated with weight change. Dimension 1 was positively weighted by mood (0.73) and self-efficacy (0.79); dimension 2 was positively weighted to change in physical activity (0.58) and fat consumption (0.55). Results provide further evidence for the importance of behavior in long-term weight maintenance, particularly physical activity and dietary fat. These findings also provide evidence for the importance of addressing psychosocial variables, in particular depressed mood and self-efficacy.

## 1. Introduction

The importance of being physically active has been well documented from a public health perspective, with increased activity associated with reduced risk for the development of chronic health conditions like cardiovascular disease [1–4]. Researchers have also reported positive mental health outcomes ranging from improved cognition to decreased depression [5, 6]. Additionally, there is a strong association between physical activity and weight management [7, 8]. Although a minimum of 150 minutes per week of moderate intensity activity is suggested to reduce health risks [9], some researchers have reported that more activity may be necessary to prevent weight gain [7] and promote weight loss or prevent weight regain after a significant loss [10–12].

It is notable that physical activity behavior has been shown to distinguish those who are successful at maintaining weight loss [13]. Other important behavioral factors associated with weight management include disinhibited

eating [12, 13], low-fat diet [14], fruit and vegetable intake [15], and self-weighing [12]. Although these behavioral variables are helpful in determining who might be more successful at weight management, they do not account for all the variance observed. As a result, researchers have also examined psychosocial variables to determine how to improve weight control outcomes.

Psychosocial factors encompass many different domains, including depressed mood, stress, and social support. Although the literature is mixed regarding the exact direction of the relationship between mood and weight, many studies report an association. According to results of the National Weight Control Registry, less depressive symptomatology was associated with significant long-term weight loss maintenance (i.e.,  $\geq 30$  lbs weight loss maintained for at least 1 year) [12]. Prospective work suggests that while baseline depressive symptoms negatively influence weight over time, baseline weight does not have a direct effect on one's mood [16]. However, in the context of purposeful weight loss,

successful loss is associated with improved mood [17, 18]. In addition to depressed mood, perceived stress has been linked with weight [19]. For example, lower ratings of baseline stress were associated with greater weight loss in one study [20]. However, the literature is mixed with some studies failing to find an association between perceived stress and body weight [21]. Finally, social support is another psychosocial variable that has been shown to be associated with improvements in weight and physical activity behavior (e.g., [22]). Psychological factors like depression and stress may interact with other theory-based variables like self-efficacy to promote participant behavior change that is associated with weight loss.

With regard to physical activity promotion and weight management, Social Cognitive Theory (SCT; [23]) and the Transtheoretical Model of Change (TTM; [24]) are discussed frequently within the literature and used to tailor interventions (e.g., [25, 26]). Both SCT and the TTM emphasize self-efficacy or one's confidence in making a particular behavioral change. Self-efficacy (eating and exercise-related) has been shown to be predictive of short-term weight change [27, 28]. Additionally, self-efficacy has been shown to be a critical intermediate variable associated with physical activity and weight loss maintenance [29]. The TTM also highlights other constructs like decisional balance, or the pros and cons of behavior change, and the processes of change (cognitive and behavioral) [30, 31]. Decisional balance and processes of change have been associated with increased physical activity and weight loss [27, 29]. However, participation in an exercise promotion trial may not always improve all theoretical constructs (e.g., [32]).

Overall, theory-based interventions targeting physical activity and body weight have been shown to be largely effective, and these interventions have been delivered via a number of channels including face-to-face, mailings, and the Internet [33–37]. Despite these studies, additional work is needed to determine the ideal components of interventions designed to promote physical activity and weight loss. In particular, there is a continued need to clarify the roles of behavioral and psychosocial variables that affect physical activity and weight management.

The *Women's Wellness Project* was designed to examine the efficacy two print-based physical activity promotion programs for women [35]. In this project, women were randomly assigned to one of three groups: (1) *Choose to Move* (CTM), a print-based physical activity intervention designed specifically for women, (2) *JumpStart*, a motivationally tailored print-based intervention, or (3) Wellness contact-control group. The interventions (see below) focused on the adoption on maintenance of physical activity and did *not* include calorie goals or weight loss targets. Since participants completed 1-year follow-up assessments, this type of physical activity trial is useful for assessing change in weight status among participants. A 1-year time point was selected as this is a designated time point for determining long-term maintenance of weight loss [12].

Given the importance of understanding individual variability in weight stability and response to physical activity interventions, we proposed to examine and identify

evidence-based constructs associated with weight stability. Therefore, we hypothesized that psychosocial and behavioral variables, selected based on research and theory (e.g., [8, 13, 27–29]), would successfully discriminate between individuals who had different patterns of weight change over time.

## 2. Materials and Method

This study was approved by the Hospital's Institutional Review Board to ensure the adequate protections for safeguarding the rights of human subjects.

**2.1. Recruitment.** Recruitment consisted of a both in-person and mass media approaches, including “information booths” in local community settings, such as supermarkets and at the local community college. Additionally, flyers were distributed in the libraries, to town employees with their paychecks, and to school department employees in their mailboxes. Mass media approaches included inserts in local, regional, and special interest newspapers and public service announcements on cable-access television and radio. The recruitment message was targeted to women and included a brief overview of eligibility requirements and study purpose. Potential participants were prompted to call a toll free number to obtain information and determine eligibility and via a brief telephone screen prior to participation.

**2.2. Exclusionary Criteria.** Healthy, sedentary women between the ages of 18 to 65 years were recruited, with sedentary defined as participating in 90 minutes or less of purposeful physical activity or 61 minutes or less of vigorous physical activity [35]. Other exclusion criteria included medical problems that could potentially impede or be exacerbated by physical activity (e.g., history of pulmonary, cerebrovascular, cardiovascular disease, severe osteoarthritis, diabetes, BMI > 40). Physician consent was required for individuals with hypertension, murmurs, and mitral valve prolapse. In addition, individuals were excluded if there was a planned move from the area within the next year, current or planned pregnancy, hospitalization for a psychiatric disorder within the last 6 months, current suicidal or psychotic episodes, or current use of certain prescription medications (e.g., mood stabilizers, antipsychotics).

**2.3. Participants.** A total of 752 women responded to the recruitment strategies for the study. See Figure 1 for a participant flow chart. Of those responding, 660 were reached and screened for eligibility, with 35% ( $N = 233$ ) being ineligible to participate due to (1) medical conditions ( $N = 100$ ), (2) being too active ( $N = 88$ ), or (3) having a BMI  $\geq 40$  ( $N = 27$ ). In addition, 18 women were excluded for “other” reasons, (e.g., age greater than 65, transportation difficulties, planned relocation, and planning to become pregnant within the next year), and 58 were not interested. Of the 369 participants who met the eligibility requirements for the study, 280 participants were randomly assigned at baseline into one of the three study arms. For these analyses,

an  $N$  of 247 will be used as this is the sample size for which we have complete BMI data at baseline and Month 12. The majority of the sample was Caucasian (94%), middle-aged ( $M = 47.5$ ;  $SD = 10.7$ ), married (65%), employed full-time (53%), and underactive ( $M = 45.4$ ;  $SD = 101.5$ ). The mean BMI was 28.6 ( $SD \pm 5.3$ ). At baseline, there were 59 (22%) normal/underweight women, 105 (39%) overweight women, and 106 (39%) obese women.

**2.3.1. Assessments and Follow-Up Rates.** The primary assessment time points were Months 3 and 12 after baseline. At these time points, participants attended an in-person assessment session and completed questionnaires and objective measures. For the purposes of these analyses, only the baseline and Month 12 values will be used. Follow-up rates were excellent, with 94% and 93% of the sample being retained at Month 3 and Month 12 assessment time points.

#### 2.4. Intervention Conditions

**2.4.1. Choose to Move ( $N = 93$ ).** *Choose to Move* was a print-based booklet developed by the American Heart Association to help women adopt and maintain physical activity. The booklet was a 12-week program targeted to women, with each week covering a topic of relevance from Social Cognitive Theory and the Transtheoretical Model such as goal setting, benefits of physical activity, increasing confidence, as well as self-report logs and self-administered worksheets. No information was included regarding calorie or fat goals.

**2.4.2. Jumpstart for Exercise ( $N = 95$ ).** *Jumpstart* was a print-based intervention that was developed and validated by researchers at the Miriam Hospital and Brown University [38, 39]. The *Jumpstart* intervention consisted of tailored expert system reports and a booklet matched to Stage of Motivational Readiness for Change [38, 39]. The expert system report consisted of pre-written counseling messages on self-efficacy, barriers, benefits, social support, goal setting, and strategies for change that were provided based on information obtained from each participant [26]. Each participant in the tailored-intervention group received a mailing 4 times during the course of the 12 months (baseline, Month 1, Month 3, and Month 6). No information was included regarding calorie or fat goals.

**2.4.3. Wellness ( $N = 92$ ).** Participants in this arm of the trial received one mailing that included a binder of women's health information, with no recommendations relating to physical activity or calorie/fat goals. The materials were compiled from reputable sources such as the American Cancer Society, Food and Drug Administration, USDHHS Office on Women's Health, and the National Mental Health Association. Sample topics included emotional and mental well-being and stress management.

#### 2.5. Measures

**2.5.1. Body Mass Index.** Height and weight were obtained at the baseline and Month 12 clinic visits. Height was assessed via a stadiometer; weight was measured via a calibrated scale. BMI was calculated using the standardized formula: weight (kg)/height (m)<sup>2</sup>. Women were categorized by weight status change from baseline to Month 12: *no change* (BMI within  $\pm 1$  unit;  $N = 154$ ; 62.4%); *increase* (BMI change  $\geq 1$  unit;  $N = 34$ ; 13.8%); *decrease* (BMI change  $\leq -1$  unit;  $N = 59$ ; 23.9%).

**2.5.2. 7-Day Physical Activity Recall (PAR) [40].** The interviewer administered PAR [40, 41], was the primary outcome measure. The PAR has established validity and reliability [40, 41], and it has been shown to be sensitive to change in studies of moderate intensity activity (e.g., [42–44]).

**2.5.3. Exercise Self-Efficacy [25].** This 5-item self-efficacy examines the respondent's confidence regarding participation in physical activity in five separate situations (e.g., vacation, bad weather, being tired, negative affect, lack of time). The scale has good internal consistency (0.82) and test-retest reliability [25].

**2.5.4. Decision-Making [45].** The 16-item Decisional Balance instrument examines participants' beliefs about the costs and benefits of engaging in physical activity. Sample items include "I would feel less stressed if I were regularly physically active" and "At the end of the day, I am too exhausted to be physically active." There are two subscales one for the "pros" or benefits of being physically active and one for the "cons" or negative factors associated with being physically active. Each subscale has demonstrated reliability (coefficient alphas of 0.79 for the costs scale and 0.95 for the benefits scale).

**2.5.5. Processes of Change [31].** This 40-item measure assesses the Processes of Change for physical activity. There are two factors, behavioral and cognitive processes, each consisting of five subscales. The internal consistency of the Processes of Change scales averaged 0.83 [31].

**2.5.6. Social Support for Exercise [46].** This social support scale is a 14-item measure that assesses the degree to which family or friends are sources of support specific to physical activity. For the purposes of this investigation, the Participation/Involvement subscale was used. Items include "During the last three months, my family/friends have exercised with me," and "During the last three months, my family/friends gave me encouragement to stick with my exercise program." This subscale has a demonstrated test-retest reliability (ranges from 0.77 to 0.79) and internal consistency (Cronbach's alpha ranged from 0.84 to 0.91) [46].

**2.5.7. Perceived Stress Scale (PSS) [47].** This 14-item measure assessed the extent to which a participant evaluated different situations as stressful (e.g., "In the last week, how often have

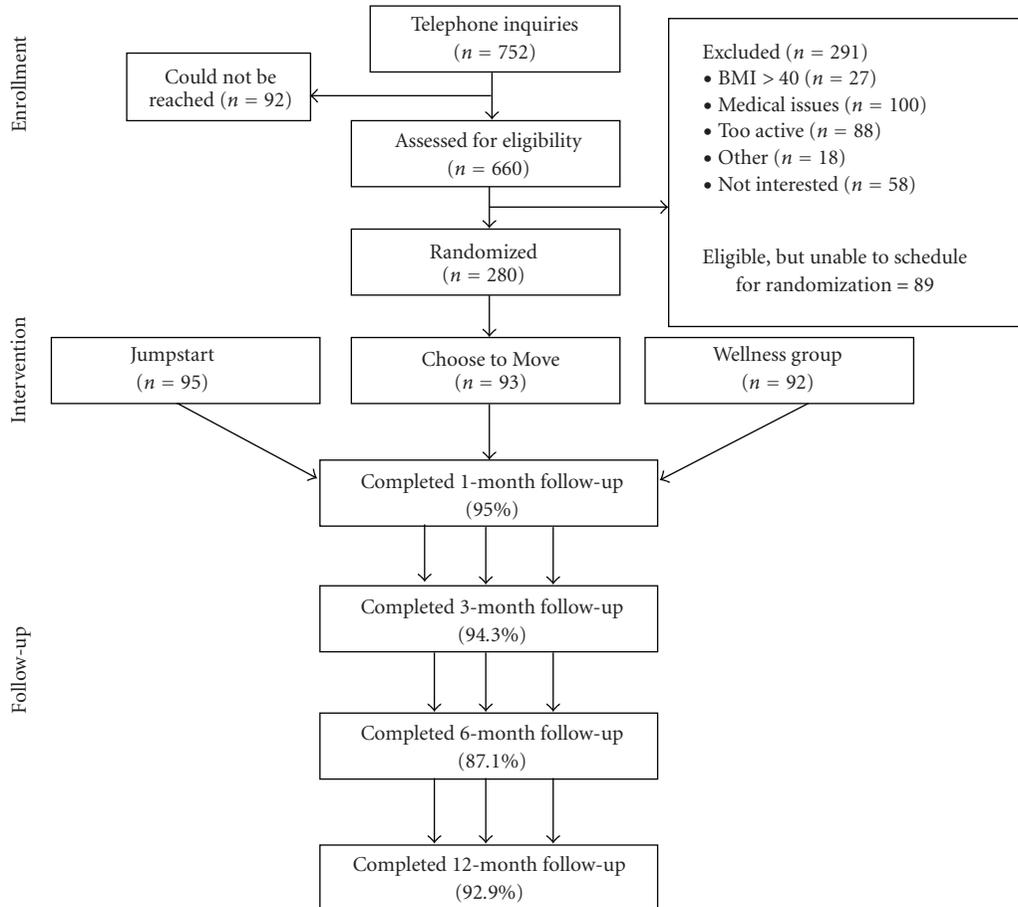


FIGURE 1: Participant flow chart.

you felt that you were unable to control the important things is your life.”). The Perceived Stress scale has been shown to have good reliability and validity [47].

**2.5.8. The Center for Epidemiologic Studies Depression Scale (CES-D) [48].** The CES-D scale is a 20-item self-report measure developed to assess depressive symptoms in the general population [48]. The CES-D scale is composed of (1) depressive affect; (2) positive affect; (3) somatic and retarded activity; (4) interpersonal problems; with  $\alpha = .84-.90$ . Sample items include, “I felt depressed,” “I felt that I was just as good as other people,” and “I felt that everything I did was an effort.” The CES-D has been shown to discriminate between psychiatric inpatient and general population samples [48].

**2.5.9. Sedentary Behavior [49].** For the purpose of this study, participants self-reported the number of hours spent watching television per week.

**2.5.10. Fruit and Vegetable Screener [50].** The Fruit and Vegetable screener assesses 10 fruit and vegetable food items over the period of the last month. It includes items assessing the frequency of eating certain foods (e.g., fruit,

juice, lettuce salad, potatoes) and the amounts consumed of each. This measure is designed to provide an estimate of the total number of Pyramid servings of fruits and vegetables consumed daily. Estimated correlations between this instrument and a recall were 0.51 for women.

**2.5.11. Fat Screener [51].** The Fat Screener is a 17-item measure designed to provide an estimate of the percent of energy from fat. This measure includes items to assess the frequency a participant consumed certain foods (e.g., margarine/butter, sausage/bacon). Responses were coded and weighted in order to estimate the percent of energy from fat. This screener was validated against two 24-hour recalls collected from a nationally representative sample in the United States and a Food Frequency Questionnaire. The Fat Screener correlations with true fat intake ranged from 0.36 to 0.59 among women [51].

**2.6. Analyses.** All analyses were performed using SAS 9.2 [52]. A list of theoretically and research-based constructs was selected to investigate which variables discriminated weight status change (i.e., stable, gain, lose) from baseline to Month 12. Change scores were calculated with change from baseline to Month 12 on the variables of interest. First,

a stepwise discriminant analysis was used to select the subset quantitative variables for the use of subsequent analysis to discriminate among the classes. Next, a discriminant function analysis using the variables identified in the stepwise discriminant analysis was conducted.

### 3. Results

**3.1. Main Trial Results.** At the 12-month follow-up, participants in all treatment arms had increased their physical activity ( $M = 140.4$ ,  $SE = 14.82$ ), with no differences between the arms [35]. There were no differences on key variables (i.e., age, BMI, baseline physical activity) between completers and noncompleters. Furthermore, there was no differential dropout between the groups. There also were no differences between the treatment arms on weight change ( $M = -0.28$ ;  $SE = 0.09$ ). Therefore, for the purpose of this paper, data will be collapsed across treatment arms.

**3.2. Stepwise Discriminant Analysis.** Based on the research literature of behavioral and psychological factors related to weight change (e.g., [12]) as well as theory (e.g., [27, 28]), we selected the following constructs as possible variables for use in discriminating among those women who lost, gained, or remained weight stable. The constructs were depressive symptoms, physical activity, sedentary behavior (i.e., TV watching), friend/family support for physical activity, perceived stress, cognitive and behavioral processes of change, self efficacy, decisional balance, diet composition (i.e., fruit/vegetable and fat consumption). See Table 1 for the change scores from baseline to Month 12.

Models were run with both stepwise and forward entries, with the same cluster of variables being produced by each model. The results of the stepwise entry will be presented here. Discriminant analyses revealed depressive symptoms ( $F(2, 223) = 3.95$ ;  $P < .05$ ), physical activity behavior ( $F(6, 442) = 3.09$ ;  $P < .01$ ), self-efficacy ( $F(4, 444) = 3.40$ ;  $P < .01$ ), fat consumption ( $F(10, 438) = 2.74$ ;  $P < .01$ ), and cognitive processes of change ( $F(8, 440) = 2.93$ ;  $P < .01$ ) as discriminating variables.

**3.3. Discriminant Function Analysis.** Tests of dimensionality identified two distinct dimensions; both of the dimensions were statistically significant. Dimension 1 ( $F(10, 456) = 2.76$ ;  $P < .01$ ) had a canonical correlation of 0.26 between the response variables and weight status classification, while the canonical correlation for Dimension 2 ( $F(4, 229) = 2.70$ ;  $P < .05$ ) was lower at 0.21. Standardized canonical coefficients for both dimensions were examined with the first dimension positively weighted by changes in mood (0.73) and self-efficacy (0.79). The second discriminant dimension was more weighted to change in physical activity (0.58) and fat consumption (0.55). The first dimension reflects a negative affect and self-confidence dimension, while the second reflects a physical activity and dietary behavior dimension. See Table 2 for the standardized pooled, within class standardized canonical coefficients, which can be interpreted similarly to standardized regression coefficients.

For example, a one standard deviation increase on the depression variable will result in a .73 standard deviation decrease in the predicted values on discriminant function 1 [53].

### 4. Discussion

The results from the discriminant function analysis indicated two statistically significant dimensions. The first dimension was a psychological dimension weighted by changes in depressive symptoms and self-efficacy for physical activity. When examining the mean changes on these variables by weight status classification, women who gained weight reported increases in depressed mood (mean = 4.47;  $SE = 1.58$ ), compared with women who lost weight (mean = 1.30;  $SE = 0.95$ ) or remained weight stable (mean = 0.47;  $SE = 0.66$ ). This finding is consistent with other studies in which depressive symptomatology was negatively associated with weight regain [12]. There are a few explanations for the association between mood and weight. Successful and purposeful weight loss is associated with improved mood [17, 18]. Other findings from a recent meta analysis suggest that there is a relationship between increased physical activity and improved mood [5]. Additionally, although psychosocial in nature, clinically, depression encompasses many physical and behavioral features. In fact, behavioral activation is often the first step in successful evidence-based treatments for depression [54]. Given the behavioral components of depression, it is not surprising that depressive symptoms also loaded at  $-.52$  on Dimension 2. These results highlight a need to include distress tolerance or some other intervention targets for managing negative mood within the context of weight and physical activity trials.

The other variable that was weighted highly on Dimension 1 was self-efficacy for physical activity. Although the research related to the construct of self-efficacy and weight loss has been mixed [55, 56], self-efficacy has been shown to be an important construct for the adoption and maintenance of physical activity [29], and weight change in short-term weight loss studies [27, 28]. The association between self-efficacy long-term weight outcomes from this physical activity-only trial provides further evidence for the importance of this construct. Self-efficacy is a construct that reflects one's confidence that they can be active despite numerous barriers [23, 57]. While self-efficacy tends to be domain specific [57, 58], there is likely overlap between one's confidence to be physically active and their confidence to perform other healthy weight-related behaviors. It is interesting to note the change scores for this construct by weight status. For women classified as losing or gaining weight, the mean change was about 0.33. However, for women classified as being weight stable, there was virtually no change on self-efficacy between baseline and Month 12 ( $M = -0.02$ ). Women who have successfully performed physical activity for a 12-month period may have already internalized their confidence to do so, which may reflect the stability of that construct over time among women who were weight stable. Future studies should investigate

TABLE 1: Change scores by 12-month weight status.

Variable	Gain			Lose			Weight stable		
	N	Mean	Std error	N	Mean	Std error	N	Mean	Std error
Depressed mood*	34	4.47	1.58	58	1.30	0.95	152	0.47	0.66
PA behavior*	34	92.79	46.96	59	170.02	37.27	154	95.90	11.21
Perceived stress	33	1.00	1.21	58	0.88	0.91	152	-0.56	0.58
Beh. proc of change	34	0.21	0.12	59	0.28	0.09	151	0.17	0.05
Cog proc of change*	34	-0.04	0.10	59	-0.16	0.08	151	-0.12	0.05
TV viewing	33	-2.15	2.56	58	-2.26	2.47	151	0.42	1.28
Self-efficacy*	34	0.34	0.16	59	0.32	0.14	151	-0.02	0.07
Decisional balance-pros	34	-0.30	0.12	59	-0.11	0.10	151	-0.21	0.06
Decisional balance-cons	34	-0.03	0.13	59	-0.16	0.09	151	0.07	0.06
Social support-PA, friends	33	1.88	1.85	56	1.25	0.96	149	0.30	0.58
Social support-PA, family	34	2.79	1.92	57	2.28	1.10	148	1.59	0.56
Fruit consumption	33	-0.55	0.70	58	0.58	0.36	153	0.06	0.29
Fat consumption*	32	-1.80	0.71	55	-0.32	0.66	149	-1.03	0.32

Note. \* Indicates variables identified in stepwise discriminant analysis.

TABLE 2: Canonical coefficients associated with each variable.

Variable	Pooled Within-Class Standardized Canonical Coefficients	
	Dimension 1	Dimension 2
Depressed Mood	0.73	-0.52
PA Behavior	0.35	0.58
Cog Proc of Change	-0.37	-0.37
Self-efficacy	0.79	0.11
Fat consumption	0.04	0.55

the longitudinal relationship between changes in physical activity self-efficacy and weight gain. For women who are gaining weight, confidence in their ability to exercise may not transfer to confidence for managing dietary behaviors.

The second dimension identified in the discriminant function analysis reflects a behavior dimension. Consistent with other studies, these results provide further evidence for the importance of behavior change (i.e., physical activity and diet) in long-term weight maintenance. In particular, women who lost weight reported, on average, 170 minutes of physical activity, in contrast to the amounts reported (93 and 96 minutes) in women who gained and remained weight stable, respectively. This result is similar to other studies indicating that physical activity behavior distinguishes successful weight loss maintainers [13]. Consumption of a low-fat diet has been shown to be an important behavioral target for weight loss/maintenance, as well (e.g., [14]). Findings from the discriminant function analysis also identify fat consumption as a distinguishing variable. However, when the means are examined, women who gained weight reported lower (-1.80) fat consumption compared with women who lost (-0.32) or remained weight stable (-1.03). It is surprising that women who gained weight from baseline to Month 12

reported greater decreases in fat consumption than women who lost or remained weight stable. This could reflect a tendency for underreporting [59–61] or a social desirability bias [62, 63] that women who gained weight may be embarrassed by their dietary intake and thus were not forthcoming about their intake. Unsuccessful dieters have been shown to misreport (i.e., underestimate) their intake by 47% compared with 19% of controls [61]. It is likely the results of the current study are related to a reporting bias, which is consistent with other studies which have found selective underreporting of fat by obese participants [60, 64]. Future studies should include more precise measures of dietary intake and behavior than the screener measure used in this study.

There are some limitations of this study which would put the findings in context. First, although weight and height were clinically measured and physical activity was assessed via an interviewer-based measure, the other measures were self-reported. A particular limitation of the measurement is the use of fruit/vegetable and fat consumption screener measures, rather than a food frequency questionnaire [65]. A more complete measure of dietary intake may have resulted in different findings for eating behaviors. Additionally, the study sample was all female and predominately Caucasian, therefore the results cannot be generalized to men nor to other races/ethnicities. Of the sample, only 13.8% gained weight over the 12-month period; despite this small number inclusion of this group provides an important comparison for the study. Finally, the participants were self-selected in that they were interested and willing to be part of a physical activity intervention trial. Anecdotally, many of the women reported joining the trial with the goal of losing weight. It is possible that the women were motivated, in general, to lose weight, and this could have influenced the associations found in this study. Nonetheless, a physical activity-only intervention trial, particularly one with >90% retention rates, provides a useful context for examining long-term weight change. This retrospective longitudinal analysis

provides a framework for examining patterns of change that can be generalized to individuals who have not had the benefit of dietary recommendations, calorie goals, and problem solving for high risk situations, as is typical for behavioral weight control interventions.

Although the variables selected for inclusion in the analyses were based on theory and evidence-based practice, the study was retrospective in design, consisting of post hoc analyses. Discriminant function analyses have great potential value, particularly in the retrospective examination of certain predictor variables [66], but have limitations. Specifically, this approach does not allow for the examination of directionality of changes nor reverse causality. For the current study, there were other variables known as important for weight loss maintenance not included in the discriminant analyses as they were not measured in the present study. Future studies should examine other psychosocial and behavioral variables of interest.

Despite these limitations, however, the paper identifies important constructs related to weight stability. This study provides further evidence for the importance of behavior in long-term weight maintenance, particularly physical activity and dietary fat consumption. These findings also provide evidence for the importance of psychosocial variables, in particular depressed mood and self-efficacy. These results give investigators signals as to the variables of importance for targeting in future physical activity trials. Not only are they important in physical activity trials, but also for weight trials. Approximately 24% of the sample lost weight (at least 1 BMI unit) over the 12-month period, despite the lack of a calorie goal, weight loss problem solving, and behavioral weight control content. Thus, almost 1/4 of women in this trial were independently making changes to be successful at weight management without the benefit of direct education and skills provided within the context of behavioral weight loss. Therefore, it is essential to better understand the strategies and steps these women are employing to learn to extend to other individuals. Better understanding of the intermediate steps women take to lose and maintain weight over a 1-year period can help elucidate the critical mechanisms for successful weight loss and maintenance.

There also are implications for the design and content of both weight management and physical activity interventions. In particular, future interventions should continue to provide education and strategies for improving self-efficacy [67], particularly in the context of weight loss and maintenance [68]. Such strategies include “modeling” or watching others perform the behavior, practicing and mastering the behavior in situations previously thought insurmountable, modifying and reinterpreting physiological states (e.g., aches/pains) to something positive (e.g., “I must be building muscle mass”) [68, 69]. Additionally, while treating depression may be outside of the expertise of health promotion professionals, interventions can still provide tools for helping patients improve mood and manage distress. In particular, mindfulness-based approaches to diet and physical activity are promising adjuncts to traditional behavioral weight control interventions [69, 70].

With the high rates of obesity [71–73], there is emerging focus on the importance of understanding individual responses to physical activity and weight loss trials. This study sheds light on individual variables that may help explain why some people experience different long-term patterns of weight change. These variables also are important for understanding the mechanisms by which individuals maintain long-term weight losses. Future studies are needed to replicate these findings in physical activity intervention trials, as these trials provide a controlled way for understanding what individuals are doing outside of the context of weight loss trials, which is more reflective of the general population. The results from this study provide further evidence of the importance of continuing to refine our behavior change interventions to assure that they contain the most relevant content and theory-based skill building. By providing this information and skill building, the negative and psychological consequences of weight gain can potentially be averted.

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## Research Article

# Impact of Regular Exercise and Attempted Weight Loss on Quality of Life among Adults with and without Type 2 Diabetes Mellitus

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**Objective.** To examine the association between exercising regularly and trying to lose weight, and quality of life among individuals with and without type 2 diabetes mellitus (T2DM). **Methods.** Respondents to the US SHIELD baseline survey reported whether they had tried to lose weight during the previous 12 months and whether they exercised regularly for >6 months. Respondents completed the SF-12 quality-of-life survey one year later. Differences between T2DM respondents ( $n = 2419$ ) and respondents with no diabetes ( $n = 6750$ ) were tested using  $t$ -tests and linear regression models adjusting for demographics, body mass index (BMI), and diabetes status. **Results.** After adjustment, exercising regularly was significantly associated with higher subsequent physical and mental component scores ( $P < .001$ ). After adjustment, trying to lose weight was not associated with higher physical component scores ( $P = .87$ ), but was associated with higher mental component scores ( $P = .01$ ). **Conclusion.** Respondents who reported exercising regularly had significantly better physical and mental quality of life, compared with respondents who did not exercise regularly. Despite exercising regularly, respondents with T2DM had significantly worse quality of life, compared with respondents without diabetes who exercised regularly.

## 1. Introduction

Diabetes mellitus is a prevalent and costly disease. Across the world, there are 285 million adults, aged 20–79 years, with diabetes [1]. This is projected to increase to 439 million people globally by 2030 [1]. In the United States, there are 23.6 million adults 20 years or older with diabetes, and approximately 90% of them have type 2 diabetes mellitus (T2DM) [2]. Approximately 24% of the 23.6 million Americans have undiagnosed diabetes which has not come to medical attention [2]. An additional 57 million people in the US have prediabetes, increasing their risk of developing frank diabetes [2]. The increasing prevalence of T2DM is directly related to an increasing rise in the prevalence of physical inactivity and obesity, with an estimated 97 million US adults being overweight or obese [3, 4]. Approximately two-thirds of US adult men and women diagnosed with T2DM have a body mass index (BMI) of 27 kg/m<sup>2</sup> or greater [5]. National

surveys have reported that 27% of US adults did not engage in any physical activity and another 28% were not regularly active [6].

With this global burden, it is important to manage and control diabetes to prevent development of complications. Regular exercise and weight management are key self-management treatments for individuals with T2DM. The American Diabetes Association (ADA) Standards of Medical Care in Diabetes [7] recommend that patients with impaired glucose tolerance or a hemoglobin A1c of 5.7%–6.4% be referred to a program for weight loss of 5%–10% of body weight and an increase of at least 150 min/week of moderate activity to prevent or delay T2DM. For patients with T2DM, lifestyle changes, including medical nutrition therapy and exercise, are recommended to achieve and maintain glycemic control [7]. Weight loss (at least 7% of body weight) is recommended for all overweight or obese individuals who have diabetes, to assist in achieving and maintaining

glycemic control. The ADA recommends that individuals with diabetes be advised to perform at least 150 min/week of moderate-intensity aerobic physical activity (50%–70% of maximum heart rate) and be encouraged to perform resistance training three times per week [7].

Individuals are often counseled by their physicians and other healthcare providers regarding weight management and exercise [8, 9]. However, the extent to which these recommendations are incorporated into daily life among individuals with T2DM and whether they impact quality of life are unknown. This study examined the association between exercising regularly and trying to lose weight and health-related quality of life (HRQoL) among individuals with and without T2DM to determine if adults who exercised regularly or attempted weight loss had better quality of life than those who did not perform these lifestyle behaviors.

## 2. Methods

The present investigation is a longitudinal analysis of the Study to Help Improve Early evaluation and management of risk factors Leading to Diabetes (SHIELD) data to assess the association between lifestyle behaviors and HRQoL. SHIELD is a 5-year, survey-based study conducted to better understand patterns of health behavior and knowledge and attitudes of people living with diabetes and those with varying levels of cardiometabolic risk.

*2.1. SHIELD Survey.* SHIELD included an initial screening phase to identify cases of interest in the general population (e.g., diabetes mellitus), a baseline survey to follow up identified cases with a questionnaire about health status, health knowledge and attitudes, and current behaviors and treatments, and annual follow-up surveys. A detailed description of the SHIELD methodology has been published previously [10, 11].

In brief, the screening survey was mailed on April 1, 2004, to a stratified random sample of 200,000 US households, representative of the US population for geographic residence, household size and income, and age of head of household [12], identified by the Taylor Nelson Sofres National Family Opinion (TNS NFO) panel (Greenwich, CT). All TNS NFO surveys were voluntary, and no special incentives were provided. A response rate of 64% was obtained.

A comprehensive baseline survey was mailed in September–October 2004 to a representative sample of individuals ( $n = 22,001$ ) who were identified in the screening survey as having self-reported type 1 diabetes mellitus or type 2 diabetes mellitus, no diabetes, or being at risk for diabetes. Each respondent group was balanced to be representative of that segment of the population for age, gender, geographic region, household size, and income for the US population, and then a random sample from each group was selected and sent the baseline survey. A response rate of 72% was obtained for the baseline survey. In August 2005, the first annual follow-up survey was mailed to all individuals selected for the baseline survey who were still enrolled in the household panel ( $n = 19,613$ ), and

a response rate of 72% was obtained. This investigation utilized the respondents who completed the baseline survey and the first annual follow-up survey.

*2.2. Study Measures.* Respondents were classified as having T2DM based upon their self-report of having been told by a doctor, nurse, or other healthcare professional that they had T2DM. A comparison cohort was identified as respondents who reported no diagnosis of T2DM, type 1 diabetes, gestational diabetes, or unspecified diabetes.

In the baseline survey, respondents answered survey questions on weight management and exercise. Respondents were asked to check one of the following statements about exercise: (1) I currently exercise regularly and have done so for longer than six months, (2) I currently exercise regularly, but have only begun doing so in the last six months, (3) I currently exercise some, but not regularly, (4) I currently do not exercise, but I am thinking about starting to exercise in the next six months, and (5) I currently do not exercise, and I do not intend to start exercising in the next six months. Respondents also answered the survey question worded as, “During the last 12 months, have you tried to lose weight?”, with the response options of “yes” or “no.”

The MOS Short-Form-12 version 2 (SF-12) was used to assess HRQoL in the follow-up survey (one year after the lifestyle behavior questions). The SF-12, the short form of the widely used SF-36, is a brief and reliable measure of overall health status [13]. The SF-12 measures eight domains of health: physical functioning, role limitations because of physical health, body pain, general health perceptions, vitality, social functioning, role limitations because of emotional problems, and mental health. The recall period was the past four weeks. SF-12 responses were scored from 0 to 100 on the Physical Component Summary (PCS) scale and Mental Component Summary (MCS) scale. Higher scores indicate better HRQoL. To simplify comparisons with the general population, norm-based scoring was used. In norm-based scoring, scores are linearly transformed to a scale with a mean of 50 and standard deviation (SD) of ten for the general population [13].

*2.3. Statistical Analysis.* The proportion of respondents reporting attempted weight loss or exercise regularly was computed for respondents with and without T2DM. Separate analyses were performed for attempted weight loss and for exercising regularly. Comparisons between respondents with and without T2DM were made using chi-square tests. For exercise, respondents who reported exercising regularly for at least six months were assessed since moderate to vigorous physical activity at least three times per week is recommended by the ADA. Linear regression models were constructed to assess the association between SF-12 PCS and MCS scores and exercising regularly (yes/no) or attempted weight loss (yes/no) adjusting for age (continuous), gender (women versus men), race (white versus other races), education (college or higher versus high school diploma or less), household income (> \$35,000 versus ≤ \$35,000), and BMI (continuous).

TABLE 1: Characteristics of SHIELD respondents with and without type 2 diabetes mellitus reporting exercising regularly or trying to lose weight.

Characteristics	Exercised regularly		Tried to lose weight	
	T2DM( <i>n</i> = 472)	No DM( <i>n</i> = 1,687)	T2DM( <i>n</i> = 1,722)	No DM( <i>n</i> = 4,288)
Age, years, mean (SD)	63.1 (11.9)*	56.3 (16.1)	58.3 (12.0)*	53.7 (15.2)
Women, %	50	54	64	65
White, %	87*	90	86*	90
Income, % with ≤ \$35,000/year	44*	31	52*	40
Education, % with no more than a high school degree	28*	19	35*	27
Baseline weight, lbs, mean (SD)	197.4 (49.6)*	178.0 (41.4)	225.4 (56.6)*	201.7 (48.0)
Normal weight (BMI <25.0 kg/m <sup>2</sup> )	17*	35	4*	12
Overweight (BMI = 25.0–29.9 kg/m <sup>2</sup> )	39	36	23	31
Obese (BMI ≥30 kg/m <sup>2</sup> )	44*	29	73*	57

\**P* < .05 for comparison of T2DM versus No DM; T2DM = type 2 diabetes mellitus, DM = diabetes mellitus, BMI = body mass index

TABLE 2: SF-12 scores for respondents with and with diabetes who did and did not regularly exercise.

SF-12 scores	Exercise regularly		No regular exercise	
	T2DM( <i>n</i> = 472)	No DM( <i>n</i> = 1,687)	T2DM( <i>n</i> = 1,940)	No DM( <i>n</i> = 5,041)
Physical component summary (PCS), mean (SD)	44.4 (11.7)*	49.3 (10.3) <sup>†</sup>	38.3 (12.6) <sup>^</sup>	43.8 (12.2)
Mental component summary (MCS), mean (SD)	52.8 (9.2)	52.8 (8.5) <sup>†</sup>	48.3 (11.5) <sup>^</sup>	49.4 (10.6)

\**P* < .001 for comparison of T2DM versus No DM; <sup>^</sup>*P* < .001 for comparison within T2DM of exercise regularly versus no regular exercise; <sup>†</sup>*P* < .001 for comparison within No DM of exercise regularly versus no regular exercise.

### 3. Results

There were 2,419 respondents with T2DM and 6,750 respondents without diabetes who completed the SHIELD baseline survey and first follow-up survey, and 20% of T2DM (*n* = 472) and 25% of no diabetes (*n* = 1,687) respondents reported exercising regularly for more than six months. Many respondents reported trying to lose weight: 71% of T2DM (*n* = 1,722) and 64% of no diabetes (*n* = 4,288) respondents. For T2DM respondents, approximately 15% were currently receiving insulin and 79% were currently receiving some type of antidiabetic medication. In comparing T2DM versus no diabetes respondents separately for exercise and weight management, significantly more T2DM respondents who reported exercising regularly were older, had lower income, had less education, and had higher baseline weight and more obesity compared with those without diabetes who exercised regularly (*P* < .05) (Table 1). A significantly larger proportion of T2DM respondents who reported attempted weight loss were older, had lower income, had less education, and had higher baseline weight and more obesity compared with no diabetes respondents who attempted weight loss. Among T2DM respondents, those who reported exercising regularly were older (63.1 years versus 59.2 years), had among them fewer women (50% versus 62%), had higher income (44% versus 56% with income < \$35,000), had more education (28% versus 38% with ≤ high school degree), and had lower baseline weight (197 lbs versus 220 lbs) and less obesity (44% versus 67%) than T2DM respondents who did not exercise regularly (*P* < .05). Among T2DM respondents, those who reported trying to lose weight were younger (58.3 years versus 64.0 years), had among them more women (64% versus 48%),

and had higher baseline weight (225 lbs versus 192 lbs) and more obesity (73% versus 38%) than T2DM respondents who did not attempt to lose weight (*P* < .05).

**3.1. Exercising Regularly.** Among respondents who reported exercising regularly, PCS scores were significantly lower among T2DM respondents (*P* < .05), and MCS scores were equivalent for both groups (Table 2). Among T2DM respondents, those who exercised regularly had higher PCS and MCS scores than T2DM respondents who did not exercise regularly (*P* < .001) (Table 2). A similar pattern of higher SF-12 scores for those who exercised regularly was observed for respondents without diabetes (*P* < .001). However, PCS and MCS scores varied by BMI category. PCS scores decreased from normal weight to morbidly obese (*P* < .001) (Figure 1), and MCS scores also decreased as weight increased, ranging from 52.6 for normal weight to 50.7 for morbidly obese (*P* < .001). Because differences existed between T2DM and no diabetes respondents for age, race, income, education, and BMI, multivariate regression modeling was performed.

**3.2. Attempted Weight Loss.** PCS and MCS scores were significantly lower among T2DM respondents, compared with no diabetes respondents (*P* < .05) (Table 3). For T2DM respondents, PCS and MCS scores were lower among those who tried to lose weight, compared with respondents who did not try to lose weight (*P* < .05). A similar pattern of lower PCS and MCS scores for those who tried to lose weight was observed for respondents without diabetes (*P* < .001). Both PCS (Figure 1) and MCS scores decreased as weight increased for respondents who reported trying to lose weight.

TABLE 3: SF-12 scores for respondents with and without diabetes who did and did not try to lose weight.

SF-12 scores	Tried to lose weight		No attempt to lose weight	
	T2DM( <i>n</i> = 1,722)	No DM( <i>n</i> = 4,288)	T2DM( <i>n</i> = 697)	No DM( <i>n</i> = 2,462)
Physical component summary (PCS), mean (SD)	39.1 (12.7)*	45.0 (11.8) <sup>†</sup>	40.6 (12.3) <sup>^</sup>	46.0 (12.0)
Mental component summary (MCS), mean (SD)	48.9 (11.2)*	49.8 (10.4) <sup>†</sup>	50.0 (11.2) <sup>^</sup>	51.2 (9.7)

\* $P < .001$  for comparison of T2DM versus No DM; <sup>^</sup> $P < .001$  for comparison within T2DM of tried to lose weight versus no attempt to lose weight; <sup>†</sup> $P < .001$  for comparison within No DM of tried to lose weight versus no attempt to lose weight.

TABLE 4: Multivariate linear regression results for SF-12 physical and mental component summary scores.

Model variables	SF-12 Physical Component Summary		SF-12 Mental Component Summary	
	Beta coefficient	<i>P</i> -value	Beta coefficient	<i>P</i> -value
Exercise regularly for >6 months (reference = no)	2.10	< .0001	1.43	< .0001
Tried to lose weight (reference = no)	0.041	.87	0.59	.013
Type 2 diabetes mellitus (reference = no DM)	2.41–	< .0001	0.52–	.034
Age, years	0.26–	< .0001	0.13	< .0001
Gender (reference = men)	2.21–	< .0001	1.69–	< .0001
White (reference = other race)	0.02–	.92	0.09–	.55
Education (reference = ≤ high school degree)	0.24	< .0001	0.15	.022
Income (reference = ≤ \$35,000/year)	1.52	< .0001	1.05	< .0001
Body mass index, kg/m <sup>2</sup>	0.44–	< .0001	–0.07	< .0001

R-square = 0.31,  $P < .0001$

MCS scores ranged from 49.6 for normal-weight respondents to 46.7 for morbidly obese respondents.

**3.3. Multivariate Regression.** Linear regression models (one for PCS and one for MCS) were done to adjust for the baseline differences in age, race, income, education, and BMI between diabetes groups. After adjusting for baseline demographics, BMI, and diabetes status (T2DM versus no DM), exercising regularly was significantly associated with higher subsequent PCS scores, indicating better physical quality of life for those who exercised regularly in both those with and without T2DM ( $P < .0001$ ) (Table 4). Respondents who regularly exercised had PCS scores that were at least double those of respondents who did not exercise regularly. After adjustment, trying to lose weight was not associated with higher PCS scores ( $P = .87$ ). Respondents with T2DM had PCS scores that were approximately half those of respondents without diabetes, after adjusting for demographics and BMI.

After adjusting for demographics, BMI, and diabetes status, regularly exercising was significantly associated with higher MCS scores, indicating better mental HRQoL ( $P < .0001$ ) (Table 4). After adjustment, trying to lose weight was independently associated with higher MCS scores ( $P = .01$ ). In general, after adjusting for demographics and BMI, respondents with T2DM had lower MCS scores than respondents without diabetes ( $P = .03$ ).

## 4. Discussion

Respondents who reported exercising regularly had significantly better physical and mental quality of life, compared with respondents who reported not exercising regularly, after adjusting for baseline differences. Respondents who reported

trying to lose weight had significantly better mental quality of life measures according to the SF-12-validated survey instrument [13]. There was no demonstrable improvement in physical quality of life, compared with respondents who did not attempt to lose weight, after adjusting for baseline differences. Respondents with T2DM who exercised regularly had worse HRQoL than respondents without diabetes who exercised regularly.

Previous investigations have demonstrated that individuals with T2DM had worse quality of life, compared with adults without diabetes or with the general population [14–18]. The present study expanded the evidence among individuals with T2DM to those who regularly exercised or tried to lose weight. Because lifestyle modifications, including exercise and weight management, are cornerstones of managing diabetes and attaining and maintaining metabolic control, it is important to understand how these behaviors impact HRQoL. This study demonstrates the increased relative physical and emotional burden of individuals with T2DM, as quality-of-life measures for the T2DM group were lower than those for respondents in the nondiabetic group, even among those who reported exercising regularly for a period of more than six months. Nevertheless, the SHIELD survey shows clear benefits of exercise, as quality-of-life measures were higher in both the T2DM and no diabetes groups who reported participating in a regular exercise regimen for this period. It is interesting to note that while attempts to lose weight did not result in improvement in physical quality-of-life measures over the survey period, the survey instrument documents psychological benefits in the form of improved mental quality of life. Both of these findings lend support to current practice and further justify recommending therapeutic lifestyle modification as a means

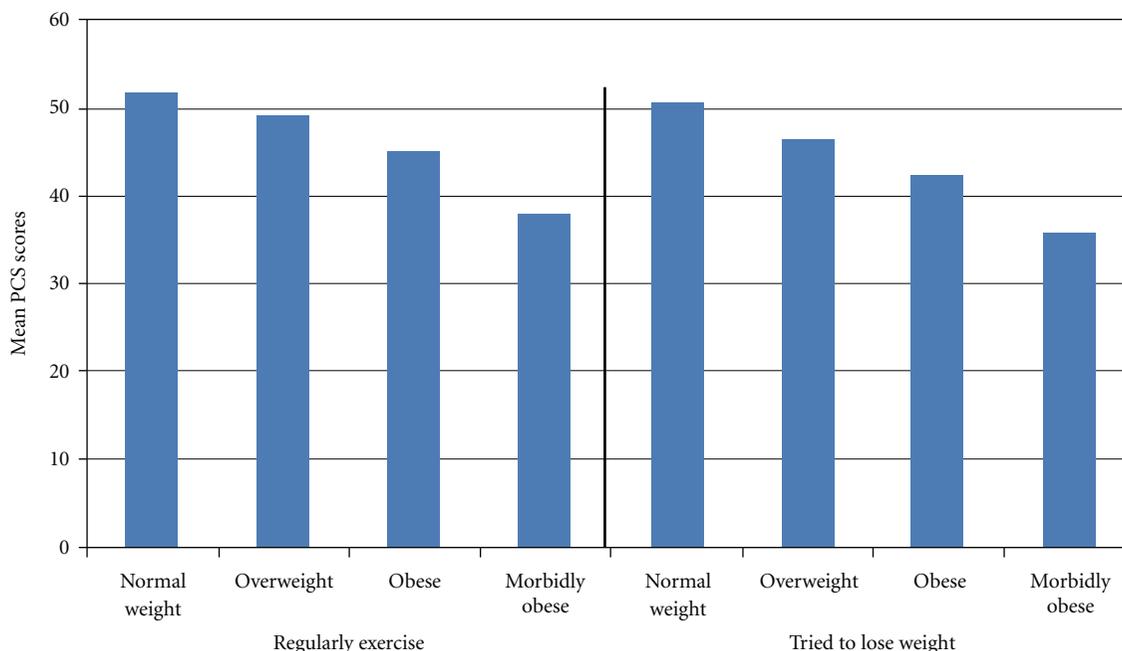


FIGURE 1: Mean Physical Component Summary scores for SHIELD respondents who reported exercising regularly or trying to lose weight by weight category. ANOVA  $P < .001$ ; normal weight = body mass index (BMI)  $< 25.0 \text{ kg/m}^2$ ; overweight = BMI between 25.0 and 29.9  $\text{kg/m}^2$ ; obese = BMI between 30.0 and 39.9  $\text{kg/m}^2$ ; morbidly obese = BMI  $\geq 40 \text{ kg/m}^2$ .

of improving quality of life for individuals with T2DM over the long term, in addition to mitigating specific health risks.

The evaluation of HRQoL in this study was performed using a standardized, validated measure of overall quality of life, so that normative-based results are provided. These findings can be used for comparative analyses with other studies and with other disease conditions. However, there are limitations to the study that should be considered. The determination of T2DM was made based upon self-report rather than clinical or laboratory measures. Exercising regularly and trying to lose weight were also self-reported and not confirmed with physical expenditure measures or actual weight loss. Other studies have found that single-response items for self-reported physical activity are valid and reflect objective measures such as  $\text{VO}_2$  max, maximal exercise treadmill test, and physical activity energy expenditure [19–22]. Household panels, like the SHIELD study, tend to under-represent the very wealthy and very poor segments of the population and do not include military or institutionalized individuals. However, these limitations are true for most random sampling and clinically based methodologies. The SHIELD population is largely Caucasian which may limit the generalizability of the study findings for minorities. Self-selection bias may be present, because respondents were those who could read and comprehend the survey.

## 5. Conclusions

Respondents who reported exercising regularly for at least six months had significantly better physical and mental quality of life, compared with respondents who did not exercise regularly. Despite exercising regularly, respondents

with T2DM had significantly worse quality of life, compared with respondents without diabetes who exercised regularly, further documenting the impact and burden of T2DM. Trying to lose weight had no impact on physical quality of life, but it did improve mental quality of life. These relationships were observed among individuals diagnosed with diabetes but the impact of exercise and weight management may be greater from a societal perspective if the high proportion of individuals with undiagnosed diabetes were exercising regularly or trying to lose weight. Based on the study findings, healthcare providers should continue to educate and encourage individuals with T2DM to exercise regularly and attempt to lose weight.

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## Research Article

# Effectiveness of a Home-Based Postal and Telephone Physical Activity and Nutrition Pilot Program for Seniors

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**Objective.** To evaluate the effectiveness of a 12-week home-based postal and telephone physical activity and nutrition pilot program for seniors. **Methods.** The program was delivered by mailed material and telephone calls. The main intervention consisted of a booklet tailored for seniors containing information on dietary guidelines, recommended physical activity levels, and goal setting. Dietary and walking activity outcomes were collected via a self-administered postal questionnaire pre- and postintervention and analysed using linear mixed regressions. Of the 270 seniors recruited, half were randomly selected for the program while others served as the control group. **Results.** The program elicited favourable responses. Postintervention walking for exercise/recreation showed an average gain of 27 minutes per week for the participants in contrast to an average drop of 5 minutes for the controls ( $P < .01$ ). Little change was evident in errand walking for both groups. The intervention group ( $n = 114$ ) demonstrated a significant increase in fibre intake ( $P < .01$ ) but no reduction in fat intake ( $P > .05$ ) compared to controls ( $n = 134$ ). **Conclusions.** The participants became more aware of their health and wellbeing after the pilot program, which was successful in increasing time spent walking for recreation and improving fibre intake.

## 1. Introduction

It is estimated that the mean energy intake of Australians increased by almost 4% from 1983 to 1995 [1]. Similar significant increases were observed in the USA between 1971 and 2000 [2]. Worldwide, diet trends have shifted towards an increased consumption of fats and saturated fats, with the level of total fat consumed now exceeding recommended levels of below 30% of the daily energy intake [3].

Diets high in fruits, vegetables, and dietary fibre are associated with lower rates of obesity and certain cancers [4]. Fruits and vegetables provide a good source of dietary fibre. Throughout the world, reported fruit and vegetable consumptions are now well below the World Health Organization's recommended levels [5]. In the USA, the consumption of fruits and vegetables declined between 1994 and 2005, with only 24.7% of the adult population consuming fruit or vegetable or both, five or more times

a day [6]. Of American adults aged 65 years and over, only 45.9% consume fruit two or more times a day and 33.7% consume vegetables three or more times a day [7]. In Australia, even after extensive social marketing campaigns promoting vegetable and fruit consumption, only 16% and 63% of older adults met recommended consumption levels for vegetables and fruits, respectively [8], while in Britain, the average intake of fruits and vegetables is estimated at three servings a day [5].

The nutritional requirements of older adults are different from those of younger adults [4], yet relatively few nutritional education programs have been specifically aimed at the elderly population group [9]. The *Dietary Guidelines for Americans* [10] recommend dietary supplementation of certain vitamins (B<sub>12</sub> and D), monitoring salt and alcohol intake, particularly its interaction with prescribed and over-the-counter medications, and participation in regular suitable physical activity. The *Dietary Guidelines for Older*

*Australians* [4] also acknowledges the different requirements of older adults, recommending four to seven servings of vegetables and two to three servings of fruit daily. These guidelines also advocate the reduction of both dietary fat and refined carbohydrate to achieve appropriate balance in macronutrient intake necessary for an acceptable body weight at this age range.

The benefits of regular physical activity for older adults are well documented. Apart from reducing obesity, it is associated with an increase in longevity and a decreased risk of many common diseases [11–13]. Studies with follow-up periods of up to 14 years have shown that sedentary older adults have greater risk of functional decline than those who are physically active [13, 14], confirming the contribution of physical activity to postponing disability and improving survival. Physical activity has been shown to enhance psychological and emotional wellbeing [15–17], as well as increasing satisfaction with life [18]. There is also evidence that it can improve quality of life by lowering levels of psychological distress and negative moods [19–21].

The published outcomes from interventions aimed at increasing older adults' physical activity levels are variable. Tailored programs have been found to be beneficial [22], whereas some home-based programs have demonstrated greater adherence than facility-based programs [23]. It has been reported that self-directed programs with some professional guidance, and programs that had four or more contacts between staff and participants, led to significant benefits [23]. Meanwhile, some low cost interventions, such as telephone counselling and video education, are able to increase physical activity in older sedentary females [24].

Interventions that aim to promote both physical activity and healthy nutrition in older adults have identified the effectiveness of written information for promoting behaviour change [25, 26]. Specific health contracts involving both the health professional and the participant are found to induce positive changes in physical activity and nutrition behaviour [27]. Health log books, where older adults identify health concerns and record how they can be addressed, have encouraged the adoption of health enhancing behaviours [28].

Health programs are clearly needed to help people understand and adopt health enhancing behaviours. However, the literature have reported relatively limited health promotion and nutrition education programs for older adults [9] and few home-based physical activity programs [29]. There is substantial scope for further development of effective strategies for older people to learn how to integrate healthy nutrition and physical activity choices into their every day life to minimise the adverse physiological changes associated with ageing [26, 30, 31]. In this paper, a Physical Activity and Nutrition for Seniors (PANS) program was piloted over a 12-week period. A mailed booklet supported by motivational telephone calls formed the main intervention. The objective of this paper is to evaluate the effectiveness of this PANS intervention for home-based 65–74 year old adults in Perth, Western Australia. A survey was conducted at both pre- and Postintervention to assess behavioural changes in walking activity and dietary outcomes.

## 2. Methods

*2.1. Participatory Action Research Approach.* The development of the PANS intervention was based on a participatory action research (PAR) approach involving systematic investigation and collaboration with the target group [32]. PAR is a form of experimental research in which the researchers and participants are partners in developing the question, intervention, and evaluation. It embraces the principles of participation, reflection and empowerment of individuals seeking to improve their situation. The process helps ensure that health promotion interventions are more relevant to the target group's needs. In the PANS program, the seniors were engaged in the development of the intervention throughout the whole process from early formative research, discussing the intervention type and its implementation, testing it and finally participating in program evaluation of its effectiveness. The PAR approach was appropriate because the program so developed was directly relevant to the older adults and it empowered them through the process of constructing and using their own knowledge.

Underpinned by the PAR approach, any effective intervention should be tailored to suit the seniors and be interactive in order to engage them. As older adults have life experiences, knowledge and habits formed over a long period of time, self help methods and advice in the form of a booklet appeared to be suitable [33]. Focus groups were conducted as part of the PAR approach to inform the appropriate level of intervention. Another component was the provision of health information that specifically addressed the seniors' concerns.

*2.2. Sampling and Recruitment Procedure.* Five hundred seniors residing within metropolitan Perth, the capital of Western Australia, were randomly selected from the Australian Federal Electoral roll which contains the name, age and address of Australian citizens over 18 years of age. Their names were matched to the Perth Electronic White Pages of telephone numbers (85% success rate). On initial phone contact, prospective subjects were required to be aged 65 to 74 years and were excluded if they considered themselves as too active or unhealthy. "Too active" was defined as "30 minutes or more of moderate physical activity on at least 5 days per week," while "unhealthy" referred to "participation in a low stress exercise program would place the person at risk or exacerbate any existing health condition". The PANS program was designed and developed for people at retirement age. The limit of 74 years was imposed to avoid the recruitment of subjects with significant health condition(s), who would find the program difficult or inappropriate. Moreover, human research ethics guidelines prohibit the participation of people at risk of adverse health event while exercising. Of the 302 contactable subjects who agreed to participate, 270 (89.4%) satisfied the selection criteria and were recruited into the study. Half the eligible sample was selected by simple randomization for the PANS program while the remaining subjects served as the control group. Written consent was subsequently sought from each participant. A total of 248 subjects (114

PANS participants and 134 controls) eventually returned the survey questionnaires, giving an overall response rate of 82%. Ethical approval was obtained from the Human Research Ethics Committee of the researchers' institution (approval number HR69/2002).

**2.3. Instrument.** A self-completed questionnaire was mailed to participants of both groups to collect data at baseline and Postintervention. Nonmonetary incentives (small gifts and vouchers from a variety store) were used to encourage the return of questionnaires. The questionnaire consisted of the following three sections, as well as a post program "exit survey" for the intervention group.

**2.3.1. International Physical Activity Questionnaire.** The International Physical Activity Questionnaire (IPAQ) has undergone extensive reliability and validity testing and has acceptable measurement properties for use in population studies of physical activity participation [34]. In this paper, the short self-administered version containing seven items was adopted. The instrument measured frequency (times and days) and duration (minutes) per week of "walking for recreation or exercise," "walking for errands," and "other moderate physical activity" which lasted for at least 10 minutes. Examples of moderate activities included swimming, dancing and cycling at a regular pace. Details of IPAQ are available from <http://www.ipaq.ki.se/ipaq.htm>. Unlike the full version of IPAQ, "walking for work" was incorporated within "walking for errands" in the short version, since the great majority of participants had already retired from the workforce. The instrument was found to be appropriate to assess walking for Western Australian seniors [35].

**2.3.2. Fat and Fibre Barometer.** The fat and fibre barometer (FFB) is a self-administered brief food behaviour questionnaire to provide rapid dietary assessment [36]. It contains 20 items to record food eating habits, with 12 questions on fat-related intake (e.g., butter, cheese, processed meat) and 8 questions on fibre-related intake (e.g., fruit, vegetables, cereal). Response values for each item range from 1 representing food behaviour associated with the highest fat or lowest fibre intake, to 5 representing the lowest fat or highest fibre intake. A "not applicable" option is also allowed for some items. The score of each component is then obtained by summing the scores from the corresponding questions. The purpose of the FFB is to classify individuals into ordinal categories according to their fat and fibre intake behaviours and not their actual consumption levels, thus providing a basis for setting dietary change goals. Its reliability, relative validity and usefulness have been demonstrated for the Western Australian population [36].

**2.3.3. Demographics and Personal Details.** Personal and demographic information was collected, including gender, age, relationship status (with partner; without partner), country of birth (Australia; elsewhere), educational attainment (primary; secondary; tertiary), and self-reported height (m) and weight (kg).

**2.4. Exit Survey.** The Postintervention survey also collected data on perceived changes in participants' health, wellbeing and fitness attributed to the intervention, intention to be active and maintain a healthy diet, as well as opinion of program components.

**2.5. Intervention.** The 12-week home-based Physical Activity and Nutrition for Seniors (PANS) intervention was designed by dietitians and physical activity specialists. The major component of the intervention was an interactive booklet that participants received in the mail. The booklet was developed through consultation with the target group. The layout and design of the booklet took into consideration the target audience, for example, larger type font with color illustrations and common nutritional related issues such as constipation.

The booklet advised the participant about physical activity and nutrition and contained information on medical conditions, the benefits of a healthy diet, physical activity guidelines and the *Dietary Guidelines for Older Australians* [4]. It also provided recipes for healthy eating and suggested opportunities for increasing physical activity especially walking. The participants were invited to identify their own health concerns and how these could be addressed through changes in nutritional and physical activity behaviour. Participants set their own healthy dietary and physical activity goals and were encouraged to record their achievements in the booklet. Further information on the development and evaluation of the interactive booklet were reported in detail elsewhere [37]. This interactive resource was accompanied by printed materials on healthy lifestyle (available from the authors upon request).

The intervention group was also provided with telephone support based on motivational interviewing [38, 39]. Five weeks following the dissemination of the booklet, the PANS participants were telephoned by final year dietetics students who were trained in motivational interviewing techniques. Each call was about 8 to 10 minutes in duration. The call intended to: (i) check on the participant's goal setting process; (ii) provide positive reinforcement that encouraged continued involvement in the intervention; and (iii) obtain feedback on the program and their use of the booklet. There was also opportunity for questions throughout the 12-week period. In addition, a pedometer was given to each PANS participant to encourage walking.

**2.6. Control Group.** The control subjects received no program materials. They completed the pre- and Postintervention surveys at the same time as the PANS participants and were similarly provided with small incentives for questionnaire completion.

**2.7. Statistical Analysis.** Descriptive and inferential statistics were first applied to contrast the demographic profile between the intervention and control groups. The main objective was to assess program effectiveness while accounting for pertinent demographic and confounding factors that

TABLE 1: Demographic profile of PANS participants and controls.

Variable	Control group ( <i>n</i> = 134)	Intervention group ( <i>n</i> = 114)
Age: mean (SD) years	72.74 (2.89)	72.19 (3.35)
Height: mean (SD) m	1.64 (0.10)	1.63 (0.10)
Weight: mean (SD) kg	72.43 (13.25)	75.70 (16.63)
Body Mass Index: mean (SD) kg/m <sup>2</sup>	27.00 (4.50)	28.37 (5.94)
Gender: male	48 (36%)	38 (33%)
Relationship status: with partner	89 (66%)	72 (63%)
Country of birth: Australia	89 (66%)	80 (70%)
Education: primary school	14 (10%)	10 (9%)
secondary/high school	80 (60%)	63 (55%)
tertiary/college	40 (30%)	41 (36%)

could affect behavioural changes. The outcomes of interest were “recreation/exercise walking” (minutes per week), “errand walking” (minutes per week), “fat intake score” and “fibre intake score” at baseline and Postintervention. The repeated measures data were analysed using linear mixed regression models with random (subject) effects to account for the inherent correlation of observations collected from the same individual, thus avoiding misleading inferences due to violation of the independence assumption. Differences between subjects as a source of extra random variation were accommodated with adjustments made in the regression coefficients and corresponding standard errors. Logarithmic transformation was also applied to the two walking variables due to their positively skewed distributions. All statistical analyses were undertaken using the SPSS package version 15.

### 3. Results

Table 1 shows the demographic profile of the intervention and control subjects at baseline. No significant difference in demographic characteristics was found between the two groups ( $P > .05$ ). The mean age of subjects was 72 years. Two-thirds were female, born in Australia and lived with a partner. The great majority of subjects (90%) had attained secondary (high) school education and beyond.

Comparisons of the four main outcomes between PANS participants and controls are summarised in Table 2. Both groups were similar in terms of dietary and walking variables at baseline. However, there were significant differences in fibre intake and recreation/exercise walking between the groups Postintervention. Paired *t*-test further indicated a significant increase in mean fibre intake in the intervention group ( $P = .03$ ) but little change in the control group ( $P = .51$ ). On average, there was a significant gain of 27 minutes per week of walking for recreation among PANS participants after the intervention ( $P = .02$ ), in contrast to a small drop of 5 minutes per week for recreational walking among the

controls ( $P = .54$ ). However, there was no change in fat intake in both groups over the 12-week period ( $P > .1$ ). Regarding time devoted to walking for errands, although the control subjects registered an average drop of almost 10 minutes per week, the intervention group exhibited only a negligible increase in errand walking, and no statistically significant differences were evident between ( $P = .07$ ) and within ( $P > .1$ ) groups after the program concluded.

Table 3 provides results of mixed regression analyses which controlled for the possible effects of demographic factors. Here, body mass index (BMI) was calculated as the self-reported weight in kilograms divided by height in meters squared. Firstly, subject heterogeneity contributed to the bulk of the residual variability, with estimated intraclass correlation ranged between 41% and 77%, thus justifying the usefulness of fitting random effects models to the repeated measures data. Secondly, the multivariate analyses confirmed the above univariate results, and demonstrated that PANS participants achieved a significant increase in fibre intake but not fat reduction when compared with seniors not on the program. At the same time, PANS led to a significant increase in walking for recreation amongst program participants, but produced little impact on improving their behaviour in terms of walking for errands. Thirdly, BMI, age and other demographic variables were found to have no significant influences on the dietary and walking outcomes.

Results from the exit survey are summarised in Table 4. The program elicited favourable (agree/strongly agree) reactions from the PANS participants. In particular, the seniors found the program and materials motivating and appropriate. A majority of them became more aware of their health and wellbeing, and claimed to continue to maintain a healthy diet and be more active after PANS. However, less participants (<50%) perceived the program as successful in terms of setting and achieving nutritional and physical activity goals, while only a quarter of seniors reported they had become involved in new activities.

### 4. Discussion

A better understanding of the health related needs of the older population can make health promotion programs more relevant [40]. When developing interventions special characteristics of seniors must be considered [41]. Including the target group in the program development and embracing their knowledge and experience are important features of a successful intervention [42]. An important principle underpinning PANS was the close interaction with the target group using elements of Participatory Action Research. The target group took part in focus groups to develop the main booklet, completed self-administered questionnaires, and were consulted on an individual basis throughout the intervention period. The combination of both print materials and motivational phone calls led to a suitable intervention, as confirmed by the positive feedback from the exit survey.

A high response rate of 82% was obtained as a result of our recruitment and retention strategy based on supportive

TABLE 2: Comparison of outcomes between PANS participants and controls.

Outcome	Control group		Intervention group		two-sample <i>t</i> -test
	Baseline	Post	Baseline	Post	
Fibre intake: mean (SD)	15.80 (3.39)	15.92 (3.27)	16.72 (2.96)	17.17 (3.07)	$P_2 = .06$ $P_3 < .01$
	$P_1 = .51$		$P_1 = .03$		
Fat intake: mean (SD)	38.71 (5.24)	38.65 (5.29)	39.13 (4.68)	39.36 (4.93)	$P_2 = .54$ $P_3 = .25$
	$P_1 = .83$		$P_1 = .44$		
Recreation/exercise walking: mean (SD) min per week	90.76 (107.27)	85.49 (98.20)	109.95 (90.46)	136.58 (111.74)	$P_2 = .16$ $P_3 < .001$
	$P_1 = .54$		$P_1 = .02$		
Errand walking: mean (SD) min per week	86.97 (103.55)	77.38 (83.89)	103.83 (112.35)	105.42 (130.30)	$P_2 = .25$ $P_3 = .07$
	$P_1 = .35$		$P_1 = .91$		

$P_1$ : baseline versus post paired *t*-test *P* value.

$P_2$ : baseline control versus baseline intervention *P* value.

$P_3$ : post control versus post intervention *P* value.

TABLE 3: Mixed regression analysis of outcomes before and after PANS intervention.

Parameter	Fibre intake		Fat intake		Recreation/exercise walking <sup>†</sup>		Errand walking <sup>†</sup>	
	coefficient	95% CI	coefficient	95% CI	coefficient	95% CI	coefficient	95% CI
Intercept	8.74	-1.55, 19.03	50.12	31.99, 68.25	1.92	-1.13, 4.98	0.45	-2.46, 3.37
PANS intervention	1.20*	0.40, 1.99	0.71	-0.69, 2.12	0.45*	0.21, 0.68	0.13	-0.09, 0.36
Age	0.11	-0.02, 0.24	-0.14	-0.37, 0.09	-0.01	-0.04, 0.03	0.01	-0.02, 0.05
Body mass index	-0.07	-0.14, 0.01	-0.04	-0.18, 0.09	-0.01	-0.03, 0.02	-0.01	-0.03, 0.02
Gender: male	-0.84	-1.69, 0.01	-0.78	-2.29, 0.72	0.24	-0.01, 0.49	0.13	-0.10, 0.37
With partner	0.01	-0.83, 0.84	-1.18	-2.66, 0.29	0.03	-0.21, 0.28	-0.06	-0.30, 0.17
Australia born	0.53	-0.31, 1.38	0.54	-0.95, 2.02	-0.17	-0.42, 0.07	-0.05	-0.28, 0.19
Secondary education	0.78	-0.63, 2.20	0.92	-1.58, 3.42	0.02	-0.42, 0.45	-0.03	-0.44, 0.38
Tertiary education	1.04	-0.43, 2.52	0.88	-1.73, 3.48	0.01	-0.45, 0.45	0.01	-0.42, .44
Intraclass correlation	0.77		0.85		0.64		0.41	

\* $P < .01$ . <sup>†</sup> logarithmic transformed. CI: confidence interval.

phone calls and reminders. Nonmonetary incentives (small gifts and vouchers from a variety store) were also used to encourage the return of questionnaires. That the program was home-based with minimal interruptions to daily life reduced barriers to participation, resulting in only a small number of refusals. Moreover, little demand was placed on the control subjects beyond the completion of two short surveys, resulting in their lower level (0.74%) of loss to follow-up than the intervention group (16%). Although the possibility of a Hawthorne effect for the improvement in the PANS group could not be ruled out, the extra attention was planned and was indeed considered as a deliberate part of the intervention.

**4.1. Outcomes and Significance.** The PANS intervention was found to be effective in increasing the recreation walking time. While walking for exercise or recreation in their neighbourhood appeals to health-conscious seniors who are likely to find other forms of physical exercise more demanding, walking to do errands is a different matter. It

normally involves longer distances from home or the need to carry goods and grocery products. Therefore, it would appear difficult to induce the seniors to raise their level of errand walking activity [43].

The PANS intervention appeared to contribute to improving dietary fibre intake. Compared to controls, the program participants recorded a significantly greater increase in fibre intake. The lack of improvement in dietary fat reduction, however, does not necessarily imply that PANS was ineffective. It is possible that a reduction in fat consumption was capped by the “ceiling effect” [44]. The baseline data indicated that the diets of both the intervention group and control group were already relatively low in fat intake. Hence, further reduction in fat was not only unnecessary but also unlikely.

Data from the post intervention exit survey supported the suitability of the program. It is noteworthy that the majority of intervention participants were satisfied and responded favourably to PANS. Most of them (76%) underlined the sensitization effect of the program, reporting that as

TABLE 4: Results of exit survey of PANS participants.

Response	Agree/strongly agree
Will still maintain a healthy diet in 6 months time	79%
Will still maintain a healthy diet in 12 months time	78%
Will continue to maintain a healthy diet when program concludes	78%
Become more aware of health and wellbeing	76%
Found the PANS program and materials motivating	76%
Did not take a long time to read the PANS booklet	72%
Booklet feedback form did encourage me to read the booklet	70%
More likely to do something about my health and wellbeing	64%
Will continue to be more active when the program concludes	60%
Will be more active in 6 months time	58%
Am generally more active	57%
Walk more often	57%
Feel healthier since starting PANS	54%
Will be more active in 12 months time	51%
Could get more done in a day	49%
Had set some nutritional goals	43%
Had reached some of these nutritional goals over the last 10 weeks	42%
Have changed diet since starting PANS	41%
Had set some physical activity goals	35%
Had reached some of these physical activity goals the last 10 weeks	33%
Become involved in new activities	25%

a consequence they had become more aware of their health and wellbeing. A great proportion (78%) of participants felt confident they would continue to observe and maintain a healthy diet after conclusion of the program.

**4.2. Limitations.** Several limitations might compromise the generalizability of the pilot findings. Although the Australian Federal Electoral roll provided a comprehensive database from which to randomly select a representative sample of potential subjects, a 2 : 1 female-to-male ratio for participants was obtained. Males have been shown to be more resistant to recruitment into research studies and walking programs in particular [45]. Self-selection bias was minimised through our randomised study design, but participation was voluntary and reporting bias still posed a threat to the validity of self-reported dietary and physical activity outcomes because of overestimation [46]. Nevertheless, the self-reported data would still be sufficiently reliable for monitoring behavioural changes [47], which formed the basis of our evaluation.

To avoid the festive season, PANS was conducted during spring and restricted to 12 weeks. The duration of the intervention might not be sufficiently long to reflect behaviour change, especially in the case of fat reduction. A longer sustainable program should be considered, though it might increase the likelihood of attrition for seniors.

In this paper, we focused on the assessment of walking activities using IPAQ because responses from initial focus group participants indicated a preference to avoid the sensation of a fast-beating heart. The benefits of walking was emphasised and highlighted in our printed promotional material. A pedometer was given to each PANS participant to encourage walking. Other modes of moderate activities should be considered in future programs.

The fat and fibre barometer, which focuses on habitual fat- and fibre-related food behaviours, is a short and easy to use dietary assessment tool with good reliability. However, a more accurate measure of dietary intake is desirable to determine changes in food and nutrient intake pre- and post-intervention.

## 5. Conclusions

The PANS program was specifically tailored for seniors. Its development followed detailed consideration of the literature and careful consultation with the target group. This pilot program provided a practical home-based method for mobilising older people. The participants became more aware of their health and wellbeing after the intervention, which was successful in improving dietary fibre intake and walking for recreation. It is recommended that the PANS intervention be replicated on a larger scale.

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## Research Article

# Utility of Accelerometers to Measure Physical Activity in Children Attending an Obesity Treatment Intervention

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**Objectives.** To investigate the use of accelerometers to monitor change in physical activity in a childhood obesity treatment intervention. **Methods.** 28 children aged 7–13 taking part in “Families for Health” were asked to wear an accelerometer (Actigraph) for 7-days, and complete an accompanying activity diary, at baseline, 3-months and 9-months. Interviews with 12 parents asked about research measurements. **Results.** Over 90% of children provided 4 days of accelerometer data, and around half of children provided 7 days. Adequately completed diaries were collected from 60% of children. Children partake in a wide range of physical activity which uniaxial monitors may undermonitor (cycling, nonmotorised scootering) or overmonitor (trampolining). Two different cutoffs (4 METS or 3200 counts·min<sup>-1</sup>) for minutes spent in moderate and vigorous physical activity (MVPA) yielded very different results, although reached the same conclusion regarding a lack of change in MVPA after the intervention. Some children were unwilling to wear accelerometers at school and during sport because they felt they put them at risk of stigma and bullying. **Conclusion.** Accelerometers are acceptable to a majority of children, although their use at school is problematic for some, but they may underestimate children’s physical activity.

## 1. Introduction

Accelerometers provide an objective measure of habitual activity which is not dependent on self-report, and are superior to pedometers because they measure the intensity of physical activity as well as frequency [1]. They are small portable devices, particularly suitable for measuring physical activity in free-living living conditions [1]. Research using accelerometers has escalated since the mid 1990s [2].

Accelerometers operate on the principle that they measure change in velocity over time (acceleration) (m.s<sup>-2</sup>), enabling intensity of physical activity to be quantified [3]. Accelerometers can be uniaxial, usually sensitive to movement in the vertical plane, or biaxial or triaxial, with movement also detected in the anteroposterior and/or lateral planes [4]. A known limitation with uniaxial (vertical) accelerometers is that they underestimate nonambulatory

activities that do not involve vertical movement of the trunk (when waist mounted) such as cycling [4]. Triaxial accelerometers have a theoretical advantage over uniaxial monitors to capture non-ambulatory activities, although in reality they provide similar information due to dominance of detecting movement in the vertical plane [4].

Studies of the validity and reliability of accelerometers in children and protocols to standardise their use are available [4–6]. “Accelerometer counts” have been calibrated against energy expenditure [3], and researchers have published thresholds of activity counts equating to different intensities of physical activity [7–9]. There has been a focus on measuring moderate to vigorous physical activity (MVPA), as the level of physical activity deemed to improve health. Activities which constitute MVPA comprise brisk walking, jogging, and running [10]. However, there remains a lack of consensus in defining the intensity of physical activity

with accelerometers, which is making comparison between studies difficult. For example, in UK school children there is a wide variation in the proportion reaching the Department of Health's [11] recommendation of 60 minutes of moderate intensity activity per day, from 2.5% in 11 year olds [12] to 92% in 13-14 year olds [13]. This large difference is thought to be due to different thresholds of accelerometer counts used to define moderate intensity activity.

The utility of an instrument includes factors relating to first, the monitor, such as technical limitations and data loss due to malfunction, and second, the participants, including adherence to data collection protocols and use of the monitor within their social context [14]. A study of the feasibility of using accelerometers in a population-based cross-sectional study of young adolescents shows data loss due to malfunction in 8.5% of participants, and 50% of the remaining students had the full 7 days of recording [15]. Using accelerometers in intervention studies to measure change in physical activity requires multiple testing and poses potentially greater practical challenges for researchers.

We have previously reported the evaluation of "*Families for Health*", a new group-based intervention for the treatment of childhood obesity for 7–11 year old children and their parents [16]. This paper gives further details on the practicalities of using accelerometers to measure change in habitual physical activity, providing new insight into their utility in children who are obese.

## 2. Methods

Data in this paper were gathered as part of the evaluation of "*Families for Health*", a treatment intervention for children who were obese or overweight and their parents from Coventry (England) [16]. Two "*Families for Health*" programmes were run. The first group of families commenced the programme in September, with followup in December and June; and the second group of families started the programme in January, with followup in April and October. These months are provided in order to understand any potential seasonal effect [12].

**2.1. Data Collection with the Accelerometers.** Children's physical activity levels were measured using a 7-day recording with a uniaxial (vertical) accelerometer with step-count function (GT1M Actigraph, Fort Walton, Florida) at three timepoints: baseline, end-of-the programme (3-months), and 9-months. As far as was practically possible, children wore the same monitor (serial number) at each time point, to remove "between unit" variation. Children were asked to wear the accelerometers during waking hours, removing them at bedtime and also during bathing and swimming, since they are not waterproof. The accelerometer was worn on an elastic belt around the waist, positioned on the right hip.

A recording over 7 consecutive days provides a reliable estimate of usual physical activity in children allowing for differences between weekday and weekend [17]. The data collection interval was 60 sec, chosen to allow the storage

of a week of data. We acknowledge that this epoch length (rather than a shorter epoch length) may underestimate MVPA [4]. Children wore the monitor for a day before the data collection started in order to allow for habituation. A 3% increase in normal levels of activity has been found on the first day of recording in children [6].

**2.2. Children's Diaries.** Children, sometimes with help from parents, completed an activity diary alongside the accelerometer for 7 days (see the appendix). This was a pictorial "tick box" diary recording activities each hour, with a column for free text additional comments. There was also a space to record the time the accelerometer was put on and taken off. The purpose of the diary was to aid interpretation of the accelerometer output.

**2.3. Analysis of Accelerometer Data.** Not all the accelerometer records were complete. We included a child's record in the analysis if there were at least 4 complete days of data available, taken as the minimum needed to obtain a reliable measurement of habitual physical activity in children (reliability of 0.80) [17]. We defined a complete day as one where there was  $\geq 7$  hrs of data, after excluding periods in the day when the accelerometer appeared not to have been worn. Although 10 hours of worn time is often used, the reliability between 7 and 10 hours is not substantially different [18, 19]. In practice, wear time was usually greater than 7 hours.

Nonwear time was identified from the data by periods of  $\geq 20$  minutes of consecutive zero counts, making it unlikely that the monitor was worn [20, 21]. There is, however, no consensus for the minutes of continuous zeros for identifying non-wear time, ranging from 10 minutes [12] to 180 minutes [15] in studies in children. In some cases, the number of minutes has not been specified [19].

At each time point for each child, the mean accelerometer counts per minute and the mean daily step count were calculated. The mean daily time spent in moderate and vigorous physical activity (MVPA) was calculated using two different thresholds for MVPA, which are in use for the Actigraph:

(i) *Freedson Equation* (See [3, 7]). Activity counts were translated into METs using the Freedson equation with 4 METs used as the cutoff for MVPA.  $\text{METs} = 2.757 + (0.0015 \times \text{counts} \cdot \text{min}^{-1}) - (0.08957 \times \text{age} [\text{yr}]) - (0.000038 \times \text{counts} \cdot \text{min}^{-1} \times \text{age} [\text{yr}])$ .

(ii) *Puyau* (See [8]). An activity count of  $\geq 3200 \text{ counts} \cdot \text{min}^{-1}$  was used as the cut-off for MVPA. Minutes spent in light physical activity was also calculated using Puyau's cut-off of 800 to 3199 accelerometer counts.

**2.4. Statistical Analysis.** To account for the hierarchical nature of the data induced by family clustering we fitted linear mixed models with random family effects to examine the differences between baseline, the end of the programme and 9-month followup, for counts per minute, minutes of

MVPA, minutes of light physical activity, and stepcounts. Analyses were conducted using SAS version 9.

**2.5. Interviews with Parents.** Semistructured interviews with 12 parents were carried out at their home by one of the authors (WR) just after the “*Families for Health*” programme. Purposive sampling was used to select a range of parents [22]. Interviews obtained parents’ perceptions of the research measurements, which were required to optimise data collection and minimise respondent burden in subsequent research [23]. The stem question was “*What did you think of the research aspects of the programme, such as the measurements of height, weight and waist; questionnaires and interviews; and activity monitor?*”

Interviews were recorded, transcribed and analysed using the Framework Approach [24], using NVivo (Version 7). Only qualitative data with bearing on the use of accelerometers are presented.

**2.6. Group Interviews with Children.** Group interviews were also carried out with 16 children at the end of the programme. No child mentioned the accelerometers and so these did not provide any information and will not be discussed further.

**2.7. Ethical Approval.** This study was approved by Coventry Local Research Ethics Committee.

### 3. Results

**3.1. Participants.** 28 children (9 males, 19 females) aged 7–13 years who were overweight or obese [25] were recruited to the “*Families for Health*” intervention, completing baseline measurements. 22 children also completed followup measurements both at the end of the programme and at 9-month followup.

**3.2. Wearing of Accelerometers.** At each time point, around half of the children had accelerometer data for all 7 days ( $\geq 7$  hrs worn time per day): 46% (13/28) at baseline, 41% (9/22) at the end of the programme, and 50% (11/22) at the 9-month followup. Over 90% of children had at least 4 days of data: baseline 93% (26/28), end-of-programme 96% (21/22), and 9-month follow-up 91% (20/22). Most records included at least one valid weekend day: baseline 86% (24/28), end-of-programme 86% (19/22), and 9-month follow-up 86% (19/22).

There were five records (from five different children) with less than 4-days data. In four cases this was because the child had not worn the accelerometer for sufficient days and in one case it was because the battery in the accelerometer failed.

**3.3. Completion of Diaries.** Adequately completed activity diaries (all days completed) were available from 68% (19/28) of children at baseline, 64% (14/22) at the end-of-programme, and 55% (12/22) at the 9-month followup. The other diaries were either not returned at all ( $n = 6$ )

or completed poorly ( $n = 21$ ) with days missing and/or lacking any detail in the final column about what children were doing.

**3.4. Interpreting Accelerometer Data.** Table 1 gives the changes in children’s physical activity after participation in the childhood obesity treatment programme. No significant change from baseline was demonstrated in the average minutes spent per day in MVPA at the end of the “*Families for Health*” intervention or at the 9-month followup using either method of calculation. Accelerometer counts per minute did not change significantly either. The average daily step count was unchanged at the end of the programme, but increased significantly at the 9-month followup. This increase may indicate that children were becoming more active in daily living, although this activity was not of sufficient intensity to be picked up by change in the summary measures from accelerometer activity counts.

The children from the two pilot groups of “*Families for Health*” differed significantly in their response from baseline to the end of the programme, but not from baseline to the 9-month followup. For example, children from Group 1 reduced their mean daily MVPA using the Freedson equation from 71 minutes in September (baseline) to 64 minutes in December (end of programme) ( $-7$  mins, 95% CI  $-22$  to  $6$ ), whereas Group 2 showed a significant increase from 40 minutes in January (baseline) to 55 minutes in April (end of programme) (15 mins, 95% CI  $1$  to  $30$ ) ( $P = .028$ ). Likewise, there were similar differences for the accelerometer counts, with Group 1 showing a reduction of  $-87$  counts $\cdot$ min $^{-1}$  (95% CI  $-180$  to  $7$ ) from September to December, whereas Group 2 had an increase of  $157$  counts $\cdot$ min $^{-1}$  (95% CI  $-44$  to  $358$ ) from January to April ( $P = .015$ ). This may reflect a seasonal effect, with less activity in the winter months, rather than any differential impact of the programme [12].

The difference in the mean MVPA calculated by the two methods was striking: 60.2 versus 15.9 minutes at baseline (Table 1). Using the Freedson equation the cut-off point of 4 METS equated to a mean activity count of  $1834$  counts $\cdot$ min $^{-1}$  at baseline, although this ranged from  $1510$  counts $\cdot$ min $^{-1}$  for the youngest child (7 yrs) to  $2515$  counts $\cdot$ min $^{-1}$  for the oldest child (13.7 yrs). Thus the activity count which defines MVPA is much lower using the Freedson equation [3, 7] in comparison with the  $3200$  counts $\cdot$ min $^{-1}$  recommended by Puyau [8]. As a consequence, at baseline 10 of the 26 (38%) children met the daily recommendation of 60 minutes of moderate intensity physical activity [11] when the Freedson equation was used, whereas no children met this recommendation when a cut-off of  $3200$  counts $\cdot$ min $^{-1}$  was used.

A number of children had very high peak activity counts (counts $\cdot$ min $^{-1}$ ) for some days. Greater than  $20,000$  counts $\cdot$ min $^{-1}$  is considered the threshold for biological plausibility for the Actigraph [26], above which data would be invalid. Recordings showing these levels of accelerometer counts were explored using visual inspection of the data alongside the diary. Figure 1 shows an example in which this child reached  $28,000$  counts $\cdot$ min $^{-1}$  between 3–4 pm. The diary showed that this child was participating

TABLE 1: Children’s habitual physical activity recorded by an accelerometer (Actigraph), at baseline (0-months), end-of-programme (3-months), and nine-month followup in 22 children (intention to treat analysis).

	0-months	3-months	9-months	0–3 month change ( $n = 20$ )		0–9 month change ( $n = 19$ )	
	Mean (SD) ( $n = 18$ )	Mean (SD) ( $n = 18$ )	Mean (SD) ( $n = 18$ )	Mean (95% CI)	$P$ value	Mean (95% CI)	$P$ value
MVPA-Freedson (mins/day)	60.2 (35.1)	65.4 (37.5)	62.8 (33.9)	6.4 (−6.7 to 19.4)	.320	3.3 (−10.1 to 16.6)	.612
MVPA-Puyau (mins/day)	15.9 (11.7)	18.6 (12.6)	17.8 (11.2)	2.9 (−2.3 to 8.1)	.258	2.3 (−3.4 to 8.0)	.405
Light-Puyau (mins/day)	142.3 (42.9)	144.2 (47.1)	152.4 (40.6)	7.0 (−15.5 to 29.4)	.523	10.8 (−8.2 to 29.8)	.247
Accelerometer Counts (counts·min <sup>−1</sup> )	581 (197)	595 (229)	593 (151)	23 (−86 to 132)	.663	10.3 (−65 to 86)	.778
Step count (steps/day)	7455 (2648)	8153 (2358)	8953 (2054)	819 (−245 to 1884)	.124	1549 (653 to 2444)	.002

MVPA: Moderate & vigorous physical activity; \*Mean data only on 18 children who had at least 4-days of data at each time-point, differences done on  $n = 20$  for 0 to 3 month change, and  $n = 19$  for 0–9 month change.

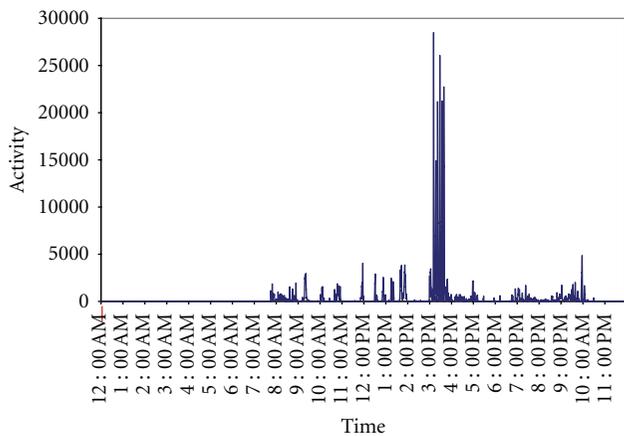


FIGURE 1: Record from the Accelerometer (activity counts) at the 9-month followup of a Child (16B) whose diary indicated that they were trampolineing from 3–4 pm.

in trampolineing at school (see the appendix). Four children specifically mentioned trampolineing in their diary, suggesting that this is a common activity. At least two other children also had trampolines in their gardens, and in one diary “*playing in garden*” was recorded at the time when there were very high peak counts, indicating that they may have been on their trampoline. One other child with very high activity counts did not return her diary but her mother at interview commented about the trampoline in the garden: “*She’s like ‘Mum I’m going to go out and do my exercise ‘cos it’s light’ and every night she’s in the garden on the trampoline, she loves it.*”

The four records where trampolineing was verified by the diary were analysed both with and without values above 20,000 counts·min<sup>−1</sup>, resulting in a mean reduction of 181 counts·min<sup>−1</sup> for the daily record and 50 counts·min<sup>−1</sup> when averaged over the weekly record. For the example in Figure 1, removal of six minutes of data between 3–4 pm

where the activity counts were above 20,000 counts·min<sup>−1</sup> led to a reduction from 500 to 342 counts·min<sup>−1</sup> for that day, and from 413 to 388 counts·min<sup>−1</sup> for the summary record. These high counts are not “invalid” data per se, but it is of note that trampolineing can lead to very high activity counts which can influence the summary record.

The physical activity the children were doing may also be undermonitored, due to the measurement abilities of the accelerometer used. A known limitation with uniaxial (vertical) accelerometers is that they underestimate activities that do not involve vertical movement of the trunk [4]. The diaries highlighted the wide range of activities in which children commonly partake which primarily involves horizontal movement (e.g., cycling, nonmotorised scooter riding, roller blading, ice skating) and may therefore be only partially monitored by the accelerometer (Table 2). We also asked children not to wear the monitor when swimming.

**3.5. Participant Factors—Children Not Wearing the Accelerometers.** Six parents volunteered information in the interviews about the accelerometers. Some children did not wear the accelerometers because they found them unacceptable when carrying out their usual activities of daily living including going to school, and playing sport.

**3.5.1. Removal for Sporting Activity.** Interview data confirmed that one boy was forbidden by the coach to wear the accelerometer when playing rugby, because being a contact sport it posed a risk of injury to others. Additionally, this child was a regular swimmer

(i) *The only problem was that with some of the activities that Child-4 does, he can’t really wear it so you’re not really getting the data for him when he’s doing the activities. Because he can’t wear it when he’s swimming and he was going swimming most mornings, he can’t wear it when he is playing*

TABLE 2: Children's Activity from their diary that is likely to be partially or wholly unmonitored by the Uniaxial Accelerometer.

	Baseline ( <i>n</i> = 25 with diaries)	End-of-programme ( <i>n</i> = 19 with diaries)	9-month follow-up ( <i>n</i> = 22 with diaries)
Cycling			
1 day	2 children	1 child	4 children
2 days	2 children	—	—
3 days	2 children	1 child	—
4 days	—	—	1 child
5 days	—	—	1 child
6 days	—	—	—
7 days	1 child	1 child	—
Scooter Riding(non-motorised)			
1 day	—	2 children	1 child
2 days	3 children	1 child	—
3 days	1 child	—	—
Roller Blading/ Ice skating			
1 day	2 children	—	1 child
Swimming			
1 day	5 children	3 children	8 children
5 days	1 child	—	—
Episodes of partially or wholly "Unmonitored" Activity	46	18	24

*rugby so you haven't really got a true reading of when he has done his activities. (Mother-4, Boy aged-10).*

3.5.2. *Unightly Elastic Belt.* Two parents complained that the elastic belt holding up the accelerometer was too obtrusive, and one parent suggested a clip as an alternative:

(i) *I think she did feel a bit embarrassed at first. I think when you tightened it a bit the thing [remaining elastic belt] came down, we tried to sort of shove it in the one together, she was alright after. (Mother-1, Girl aged-7).*

(ii) *I think because of the belt. You know like the pedometers maybe if it was something like that. [clip] When you've got the belt its more "ugh", you've got this big thing that goes right the way around you, and sometimes it flaps down, trying to tuck it in. (Mother-3, Girls aged 10 & 7).*

3.5.3. *Stigma of Wearing Accelerometers at School.* When one of us (WR) collected the monitors from their homes, several parents said that their child had not wanted to wear the monitor at school. One boy (aged-11) said that the accelerometer had caused him to be bullied by another pupil: "you are wearing it because you are fat". Parents raised similar issues in interviews. Girls in particular were unwilling to wear the accelerometer at school, due to stigma and bullying:

(i) *She didn't want to take it to school with her, she didn't want people knowing that she was wearing*

*it. So she only really wore it when she was at home and you were only talking about a couple of hours between coming home and going to bed again and a lot of it, 'cos of the weather and different bits and pieces, she has been sitting. And again, you know he [friend on programme] did take it to school though, but maybe it's a girl thing. To be honest her Dad turned around and said she couldn't take it to school because it could get damaged or broken. But I suppose he said that but maybe he was thinking he didn't want people saying stuff about her. (Mother-5, Girl aged-9).*

(ii) *She didn't want to wear it initially. A fitness test in a fun way may be more productive than a monitor purely because you are relying on the children wearing the monitors, not getting teased at school, filling the diary out. (Mother-6, Girl aged-7).*

(iii) *It is just getting them to put it on. School could have a lot to do with it, she is conscious because of her weight and because her t-shirt is quite tight that it is going to be showing. (Mother-3, Girl aged-10).*

She also added that wearing the accelerometer was a particular problem during sport at school, due to embarrassment:

(i) *She is bothered about wearing it during the activities like netball and things because she is*

*frightened her t-shirt is going to come up and because it is other classes, it's not just her own class. I did ask her today if she could wear it for netball tonight, I said it's only for practice, everybody knows you now, nearly everybody knows that you have got it on. So she said she might. (Mother-3, Girl aged-10).*

Accelerometers may be missing the physical activity of some of the children, either because of the technical limitations of the uniaxial accelerometer or due to children's unwillingness to wear them at school or during sport. However, around half of the children wore the monitor very conscientiously and provided 7 days of recording. As one parent reported:

*(i) I think wearing the monitors to start with made Child-19 aware that it was serious, you know that there was a reason for doing it, he never once didn't wear it, he never once said he couldn't wear it or threw a tantrum, even when he went to his Dad's. And his Dad wasn't particularly supportive of the whole thing ... even on the weekends when he was playing football with his Dad, as you know, he wore it. When we went to watch him [play in a football match] I said "have you got your monitor on?", and he was like "yeah" and showed it, so he took it seriously, he knew it was serious. (Mother-19, Boy aged-8).*

#### 4. Discussion

This paper provides insight into the utility of accelerometers for measuring activity in children (in this case, children who were overweight or obese), including the acceptability of their use; an analysis of the physical activity which may be undermonitored; the results from different data reduction methods to derive minutes of MVPA.

Around 50% of the children provided 7 days of data and 90% had  $\geq 4$  days of data (the minimum required to be included in the analysis). This compliance is similar to a study in young adolescents in which 50% had 7 days and 86% had at least 4 days of valid accelerometer data, although a higher proportion of children who were overweight (66%) versus nonoverweight (46%) had 7 days of data [15]. Our experience with the Actigraph monitor was good with only one recording lost due to a fault with the monitor. Participant factors included forgetting to put the accelerometer on but some nonuse was related to children being unwilling to wear the monitor, particularly in school, because they were too conspicuous. In some cases the accelerometer had an unintended consequence of stigmatising the children and putting them at risk of bullying. The implication for loss of data in an intervention study is important. Because of missing data, only 18 of the 22 children who completed all the other research measurements had accelerometry data at each timepoint. This is reasonably good adherence to the protocol, and suggests that accelerometers are acceptable to most children but there are some children, in particular

girls, who do not find it acceptable to wear accelerometers during their usual activities of daily living and, in some cases wearing the accelerometer was potentially harmful, because it encouraged bullying.

Accelerometers may have missed some of the physical activity that the children were engaged in for two reasons. First, children engage in a wide variety of physical activities which may not be captured by the uniaxial (vertical) accelerometer due to technical limitations [4]. Triaxial accelerometers, in principle, have a greater potential to capture the diverse activities in which children partake [18]. Second, children were not willing or able to wear them during sporting activities. For some sports children were requested to remove the monitors such as swimming (requested by the researchers) and rugby (requested by the coach), but some children were embarrassed and chose not to wear the monitor during sport at school. Thus the accelerometers are likely to have underestimated physical activity in the children in the current study, but the degree of underestimation is likely to vary between children.

UK guidelines recommend "at least 60 minutes of at least moderate intensity physical activity each day" for children [11]. The proportion of children estimated to meet this standard varies widely [12, 13]. Different conclusions may be due to different thresholds of accelerometer counts used to define MVPA [12]. In this study we had initially used the Freedson equation with a 4 METS threshold [3, 7] to derive minutes of MVPA [16]. However, we received feedback that the values for MVPA were too high, and reanalysis was conducted using a threshold of 3200 counts·min<sup>-1</sup> [8]. These two methods yielded very different results for both the minutes spent in MVPA, consistent with other studies [5, 27], and for the proportion of children reaching 60 minutes of physical activity per day. It is now accepted that the Freedson equation overestimates children's MVPA, and that the correct cut point is between 3000 to 3700 counts·min<sup>-1</sup> [5, 27]. Thus our data using Puyau's cut-off of 3200 counts·min<sup>-1</sup> for MVPA is likely to be the most accurate. Using this cutoff, none of the 26 children with 4 days of data at baseline achieved 60 minutes of daily moderate intensity physical activity, which is consistent with the low levels of physical activity in overweight and obese 11 year-old children in the ALSPAC cohort [12].

A common activity in children—trampolining—results in very high activity counts, and our data suggest that it may result in physical activity being "overmonitored". The physics of trampolining shows a peak acceleration of 4G [28], although the effect on the results from accelerometers in children is not widely discussed. Activity counts above 20,000 were recorded during trampolining, thought to be beyond biological plausibility for the Actigraph [26]. Very high activity counts with trampolining may negate the use of summary measures using raw activity counts (i.e., total daily activity counts or average counts·min<sup>-1</sup>) used in some studies with children [12], unless the trampolining data is removed prior to analysis. Trampolining could also affect the number of minutes spent in MVPA, because even gentle trampolining may take a child to an activity count above the threshold for MVPA. These findings suggest that

TABLE 3

Day: Thursday	Activity monitor put on: 7.30 am						Activity monitor taken off: 10.00 pm		What was your child doing? Please write down what your child was doing, for example watching TV, going to the park, playing football.
Time of day	 Lying down	 Sitting	 Standing	 Walking	 Dancing	 Swimming	 Riding my bike	 Running	
6 to 7 am									
7 to 8 am	Asleep, getting dressed								
8 to 9 am	Eating breakfast, doing hair								
9 to 10 am	In car, in class								
10 to 11 am	In class, break								
11 to 12 noon	In class								
12 noon to 1 pm	In class								
1 to 2 pm	Eating dinner, class, firebell								
2 to 3 pm	Class, walking to PE block								
3 to 4 pm	Trampolining								
4 to 5 pm	In car, working								
5 to 6 pm	Working								
6 to 7 pm	Working								
7 to 8 pm	Getting dressed, St Johns								
8 to 9 pm	St Johns								
9 to 10 pm	Watching TV								
10 to 11 pm									

trampolining should be given a specific column on our daily diary. Trampolining is physical activity, but further assessment of its impact on summary measures is warranted, and further consideration should be given to how best to account for trampolining in analysis. Caution must be exercised in the quality control and reduction of accelerometer data in children where trampolining is a relatively common activity.

This study has contributed an insight into the perceptions of parents on the use of the accelerometer with children who are obese. The findings are strengthened by using a diary alongside the accelerometer records to aid interpretation. Limitations of the study include that standardisation across the followup timepoints, although attempted, was not always possible due to logistics [29]. Followup was made at 3 and 9 months from baseline, whereas a 12-month follow-up is desirable in intervention studies so that results are not distorted by known seasonal changes [12]. A further limitation is that, whilst children were offered the opportunity of commenting on any aspect of the study, they were not explicitly asked about their perception of wearing the monitors in their daily living.

Researchers should be aware that not all physical activity is likely to be monitored by uniaxial accelerometers. Further validation studies in children performing activities such as scootering (non-motorised), cycling, roller blading, and ice skating should compare the output from triaxial and uniaxial monitors. Researchers must also be aware of the potential for harm, such as stigma and bullying of the obese child when they are singled out to wear the monitor to evaluate an obesity treatment intervention, and make efforts to minimise

these risks [30]. Acceptability to children, in particular girls, could be improved by using attachments other than the elastic belt, such as a clip. Improved communication with the child's school about the childhood obesity treatment intervention may also be of value to increase the acceptability of wearing the accelerometer at school. Alternatively, monitoring could be done in the school holidays throughout the intervention. Further studies with children are indicated to gain their perception of wearing the accelerometers, similar to the study in adults by Perry [14].

In conclusion, although accelerometers are recognised as an objective measure of physical activity, the analysis of the diary records and interview data suggest some issues with their use in children.

## Appendix

### Activity Diary to Use alongside the Accelerometer (Completed Here for Child 16 B when Trampolining, 3-4 pm)

See Table 3.

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## Research Article

# How Children Move: Activity Pattern Characteristics in Lean and Obese Chinese Children

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Physical activity and sedentary behavior are central components of lifetime weight control; however, our understanding of dimensions of these behaviors in childhood is limited. This study investigated free-living activity pattern characteristics and the individual variability of these characteristics in 84 lean and obese Chinese children (7–9 y) during the school day and over the weekend. Activity pattern characteristics were established from triaxial accelerometry (StayHealthy RT3). Results indicated that children's free-living activity is characterized by many short-duration, low-intensity bouts of movement. Obese children take longer rest intervals between bouts and engage in fewer activity bouts both at school and at home. Intraindividual variability in activity patterns was low during school days but high for the rest intervals between bouts and number of activity bouts per day at the weekend. Finding ways to reduce the rest time between bouts of movement and increase the number of movement bouts a child experiences each day is an important next step.

## 1. Introduction

Children do not voluntarily engage in sustained periods of constant intensity physical activity [1]. Instead, early evidence characterizing spontaneous physical activity in children has shown that children take frequent (83 to 89 bouts per hour), short-duration (mean duration of 20 to 21 s) bouts of movement of variable but mostly low intensity, interspersed by comparatively long intervals of nonactive time [2, 3]. This pattern of movement was termed the “tempo” of physical activity, that is, the frequency with which an activity event occurs and the intervals between these [2]. It has been suggested that these pattern characteristics may be physiologically more important than composite measures of physical activity. For instance, dynamic heart rate recovery times [4] were noted to be of similar length to the nonactive intervals between bouts of movement [2]. More recent evidence has shown that bouts of movement were shorter and less intense in overweight compared to lean boys [5]. Evidence from spontaneous walking in adults has

also shown that the duration of each walking bout resulted in obese adults walking about 2 hrs per day less than the lean, equivalent to approximately 3.5 fewer miles walked per day [6]. In the same study, participants were overfed for a period of 8 weeks resulting in weight gain and a decrease in the distance walked per day in the obese, suggestive of a mechanistic link between obesity, weight control, and spontaneous physical activity.

Whereas various social, psychological, and environmental factors have been shown to explain interindividual differences in childhood physical activity levels [7], intra-individual variation in free-living movement enables scrutiny of the extent to which physical activity is under biological control [8]. Available data suggests that total physical activity shows low intra-individual variation, with values between 20 and 25% in both children and adults [9, 10]. Similarly, a lack of variation in daily physical activity in response to changes in the physical environment in children has been used to support the argument that there is a physical activity phenotype [11].

What is not known is the degree to which the tempo of spontaneous physical activity varies within a child and how the tempo of physical activity differs with weight status. The primary objective of this study, therefore, was to provide information on the pattern characteristics of physical activity in lean and obese girls and boys during the school day and over the weekend and the intra-individual variation in these. Specifically, we hypothesized that (i) lean children would have more frequent and intense movement bouts and shorter intervals between these in comparison to the obese, independent of sex and location (school versus home); (ii) intra-individual variability in the pattern characteristics of physical activity would be similar in the lean and obese, independent of sex and location. To achieve this, we utilized cluster recognition algorithms to characterize the tempo of physical activity from second-by-second triaxial accelerometer output. The algorithms are based on the work of Veldhuis and Johnson [12], which were originally used to characterize the pulsatile patterns of hormone release but have since been used to identify activity pattern characteristics [3].

## 2. Materials and Methods

**2.1. Participants.** Chinese children aged 7 to 9 years were recruited from three government primary schools in Hong Kong. From a potential of 600 7- to 9-year olds, 180 volunteered to participate. Height and weight were assessed in school in all 180 pupils, and those above the 90th percentile for age- and sex-specific BMI cutoffs [13], as well as a group of age- and sex-matched lean children, were invited to join the study. Eighty-four children (42 lean and 42 obese, 50% male) agreed to have physical activity assessed for three weeks. None of the children had a history of illness or current medication use. The experimental protocols were approved by the Institutional Review Board for Human Ethics and written parental consent was obtained for all children.

**2.2. Procedures.** Following recruitment, the children met with research staff in the early morning at school prior to the start of lessons. Baseline anthropometric measurements were taken on the first day, and the children were instructed as to the correct care and usage of the accelerometer. All children were asked to wear the accelerometer for three weeks with 9 of the possible 15 weekdays and 3 of the possible 6 weekend days randomly chosen for each child and used for the analyses.

**2.3. Anthropometric Measurement.** Body mass was determined barefoot and in light clothing with an accuracy of 0.1 kg using digital scales (Tanita TBF-401, Japan). Height was measured with an accuracy of 0.1 cm on a fixed stadiometer (Invicta 2007246, Leicester, UK). The children were assessed barefoot and placed in the Frankfort position. BMI was calculated as  $\text{kg/m}^2$ . Waist circumference was measured at the narrowest point between the bottom of the ribcage and the top of the iliac crest and taken at the end of expiration [14]. Hip circumference was measured at the level of the greater trochanters, where the buttocks protruded

most [14]. Each circumference was taken twice and recorded to the nearest 0.1 cm.

**2.4. Measurement of Physical Activity.** A triaxial accelerometer (RT3, StayHealthy Inc., USA) was used to assess physical activity. This small, light piezoelectric device is designed to detect accelerations in three axes and combine these to provide a triaxial vector magnitude count. The RT3 has been shown to be a valid and reliable device for assessing physical activity in Caucasian and Chinese children [15–17]. Intermonitor variability, however, does exist [18], and in an attempt to counter this we ensured that each child used the same device throughout the measurement period (changed only if the device was not working satisfactorily). Additionally, before commencement and at the finish of each measurement day, every RT3 device was checked to determine the deviation in activity counts for each axis. Devices were passed if all axes were kept within  $\pm 5$  counts, which ensured minimal Intermonitor variability. The study began with 40 RT3 devices, and four failed the Intermonitor variability check during the course of the study, leaving 36 devices by the end of the study. After the Intermonitor variability check, devices were initialized according to manufacturer specifications and set in the vector magnitude, 1-s epoch mode. The RT3 was placed in a close-fitting bag, attached to a belt, and fastened firmly on the right hip, immediately superior to the iliac crest on the midaxilla line.

The children were asked to wear the device at school from 7.30 am until they returned home, which was usually 4.30 pm. On the weekend, they were asked to wear the device from the moment they got out of bed until when they went to bed in the evening. A daily monitoring period of 9 hours was delineated by the memory capacity of the accelerometer. To try to control wear time, we considered periods of consecutive zeros exceeding 60 minutes as nonwear time. Four children recorded a day with more than 60 minutes of consecutive zeros, and when asked about these periods they all reported taking the monitor off. The data for these days were rejected and replacement measurement days added.

Bouts of activity were identified using cluster identification [12]. This method involves using a series of algorithms to search for significant increases and decreases within the data series. These peaks and troughs are identified and classified. Identification and classification is based upon the threshold values which we have previously published [17], where nonactive behavior is defined as  $< 7.0 \text{ RT3}_{\text{vmag}} \cdot \text{s}^{-1}$ ; low-intensity activity is defined as  $7.0$  to  $< 31 \text{ RT3}_{\text{vmag}} \cdot \text{s}^{-1}$ , moderate intensity as  $\geq 31$  to  $< 68.5 \text{ RT3}_{\text{vmag}} \cdot \text{s}^{-1}$ , and vigorous intensity activity is defined as  $\geq 68.5 \text{ RT3}_{\text{vmag}} \cdot \text{s}^{-1}$ . A bout was, therefore, defined as a continuous segment whose element value was above  $h$ , the preset nonactive threshold  $7.0 \text{ RT3}_{\text{vmag}} \cdot \text{s}^{-1}$ . The duration of each bout was denoted as  $T_d$ , and the duration of the nonactive interval between two adjacent bouts was denoted as  $T_i$ ; the maximum element value or peak amplitude of an activity bout was denoted as  $V_p$ . A program was written in MatLab Version 7.0 (The MathWorks, Inc., USA) to process the data series in the manner explained. The variables computed by the program include the total number of bouts per day, mean duration of

TABLE 1: The physical characteristics of the participants.

	Lean ( $n = 42$ )	Obese ( $n = 42$ )
Age (y)	8.58 $\pm$ 0.45 (7.97 to 9.39)	8.58 $\pm$ 0.55 (7.39 to 9.57)
Height (cm)	130.7 $\pm$ 5.8 (166.5 to 144.2)	133.2 $\pm$ 5.1 (121.2 to 144.0)*
Body mass (kg)	26.8 $\pm$ 3.6 (19.7 to 33.4)	39.5 $\pm$ 5.8 (28.0 to 51.7)**
BMI (kg/m <sup>2</sup> )	15.6 $\pm$ 1.5 (12.5 to 18.0)	22.2 $\pm$ 2.5 (18.5 to 28.3)**
Waist (cm)	55.9 $\pm$ 3.0 (50.2 to 63.1)	70.1 $\pm$ 7.5 (57.8 to 87.9)**
Hip (cm)	67.2 $\pm$ 4.0 (68.6 to 73.5)	81.0 $\pm$ 5.9 (58.6 to 94.5)**

Values are expressed as mean  $\pm$  SD (and range).

\*significant difference between lean and obese,  $P < .05$ ; \*\*significant difference between lean and obese,  $P < .001$ .

daily bouts in seconds (s), mean duration of the rest intervals between bouts in seconds (s), and the mean peak amplitude of daily bouts ( $RT3_{vmag} \cdot s^{-1}$ ). We also report the total minutes spent sedentary, in low, moderate, and vigorous activity for lean and obese. Data for the school days and home were computed separately.

**2.5. Statistics.** Descriptive characteristics (means and SD) were calculated for all key variables. Baseline anthropometric data were compared between the lean and obese using one-way analyses of variance. Factorial analyses of variance with repeated measures were used to determine the main effects of weight status (lean and obese), sex and location (school versus home) on activity pattern characteristics, and the variance in these activity pattern characteristics (expressed as the coefficient of variation). Interactions and main effects were deconstructed using analysis of simple main effects. Significance was set *a priori* at  $P < .05$ .

### 3. Results

Eighty-four children (42 lean and 42 obese) completed the anthropometric assessment. The physical characteristics of these children are presented in Table 1. There was no significant difference in age, although the obese were taller and heavier and had a greater waist and hip circumference compared to the lean.

Physical activity pattern characteristics derived from the bout identification algorithms are presented in Table 2. All 84 children completed the school-day monitoring, whilst 40 lean and 39 obese children completed the weekend monitoring. Factorial ANOVAs revealed significant main effects for location (school versus home) for the number of activity bouts ( $F(1,75) = 79.58$ ;  $P < .001$ ,  $\eta^2 0.515$ ), the mean length of activity bouts ( $F(1,75) = 9.93$ ;  $P < .01$ ,  $\eta^2 0.117$ ), and the rest interval between bouts ( $F(1,75) = 21.76$ ;  $P < .001$ ,  $\eta^2 0.225$ ). Followup analyses indicated that the number and length of activity bouts were greater at school than at home, whilst the rest intervals were longer at home compared to school (see Table 2).

A significant main effect for weight status was apparent for the number of activity bouts per day ( $F(1,75) = 38.48$ ;  $P < .001$ ,  $\eta^2 0.275$ ), with the lean engaging in more bouts of activity during school and at home in comparison to the obese ( $P < .05$ ). A significant main effect for weight status was also apparent for the duration of rest intervals between bouts ( $F(1,75) = 11.74$ ;  $P < .01$ ,  $\eta^2 0.135$ ), with the obese taking longer rest intervals than the lean both at school and at home ( $P < .05$ ). There were no significant location by sex interactions for any variable, or weight status by sex, but there was a significant location by weight status interaction for the duration of the rest intervals between bouts ( $F(1,75) = 8.12$ ;  $P < .05$ ,  $\eta^2 0.098$ ). Followup analyses showed that between-bout intervals were significantly longer in the obese and lean at home compared to school, but the difference between home and school was much more pronounced in the obese (see Table 2;  $P < .05$ ).

The mean minutes per day spent sedentary or in low, moderate, or vigorous physical activity are provided in Table 3. There was no main effects for weight status, sex, or location for the total minutes spent sedentary, engaged in low, moderate, or vigorous activity ( $P > .05$ ). Neither were there any interactions ( $P > .05$ ).

The intra-individual variation in day-to-day activity pattern characteristics are shown in Table 4. The factorial ANOVA revealed significant main effects for location for the variance in the number of activity bouts per day ( $F(1,71) = 55.9$ ;  $P < .001$ ,  $\eta^2 0.441$ ), the duration of bouts ( $F(1,71) = 25.3$ ;  $P < .001$ ,  $\eta^2 0.263$ ), interval between bouts of activity ( $F(1,71) = 82.9$ ;  $P < .001$ ,  $\eta^2 0.539$ ), and bout intensity ( $F(1,71) = 13.5$ ;  $P < .001$ ,  $\eta^2 0.159$ ). Followup analyses showed that variance increased at home compared to the school regardless of sex ( $P < .05$ ). The only interaction was for bout peak intensity, where a significant location by sex interaction was present ( $F(1,71) = 7.70$ ;  $P < .01$ ,  $\eta^2 0.098$ ). Followup analyses showed that intra-individual variance in the peak intensity of activity bouts was constant in boys whether at school or at home ( $P > .05$ ). In girls, however, variance in the peak intensity of activity bouts increased significantly at home in comparison to school ( $P < .05$ ).

A significant main effect for sex in intra-individual variance existed for the mean duration of an activity bout ( $F(1,71) = 3.97$ ;  $P < .05$ ,  $\eta^2 0.053$ ), where variance was greater in the girls ( $P < .05$ ). Similarly, significant main effect for sex in intra-individual variance in the peak intensity of an activity bout was apparent ( $F(1,71) = 14.22$ ;  $P < .001$ ,  $\eta^2 0.167$ ), with variance greater in the girls when at home ( $P < .05$ ).

Significant main effects for weight status were apparent in the intra-individual variance in the number of bouts per day ( $F(1,71) = 5.00$ ;  $P < .05$ ,  $\eta^2 0.066$ ) and the rest interval between these activity bouts ( $F(1,71) = 6.1$ ;  $P < .05$ ,  $\eta^2 0.079$ ). In both cases, variance was higher in the obese than the lean ( $P < .05$ ).

### 4. Discussion

Free-living movement in children has been shown to comprise combinations of movements of varying intensities that

TABLE 2: Activity pattern characteristics during school days and at the weekend in lean and obese Chinese children.

		Bouts per day	Mean duration of bouts (s)	Mean duration of between-bout intervals (s)	Mean peak intensity of bouts ( $RT3_{vmag} \cdot s^{-1}$ )
Lean ( $n = 42$ )	Weekday	961 $\pm$ 150	12.8 $\pm$ 1.6	23.7 $\pm$ 8.5	16.4 $\pm$ 2.1
Obese ( $n = 42$ )	Weekday	788 $\pm$ 220**	12.4 $\pm$ 1.5	38.5 $\pm$ 26.7**	15.2 $\pm$ 1.7*
Lean ( $n = 40$ )	Weekend	677 $\pm$ 218	13.7 $\pm$ 2.0	47.0 $\pm$ 32.2	16.4 $\pm$ 1.3
Obese ( $n = 39$ )	Weekend	483 $\pm$ 241**	14.5 $\pm$ 5.9	134.2 $\pm$ 167.8*	16.7 $\pm$ 4.9

Values are expressed as mean  $\pm$  SD.

RT3 intensity cutoffs ( $RT3_{vmag} \cdot s^{-1}$ ): sedentary  $<7.0$ ; low intensity  $\geq 7.0$  to  $<31.0$ ; moderate intensity  $\geq 31.0$  to  $<68.5$ ; vigorous intensity  $\geq 68.5$ .

\*significant difference between lean and obese,  $P < .01$ ; \*\*significant difference between lean and obese,  $P < .001$ .

TABLE 3: Total minutes per day sedentary, in low, moderate, and vigorous activity in lean and obese children by location.

		Sedentary (min)	Low intensity (min)	Moderate intensity (min)	Vigorous intensity (min)
Lean ( $n = 42$ )	School	429.6 $\pm$ 33.3	82.5 $\pm$ 21.4	23.9 $\pm$ 7.8	9.1 $\pm$ 4.5
Obese ( $n = 42$ )	Home	438.4 $\pm$ 29.6	76.7 $\pm$ 20.5	23.2 $\pm$ 7.4	7.7 $\pm$ 3.1
Lean ( $n = 40$ )	School	469.2 $\pm$ 53.3	51.5 $\pm$ 30.3	15.7 $\pm$ 10.1	8.1 $\pm$ 2.7
Obese ( $n = 39$ )	Home	484 $\pm$ 83.7	42.6 $\pm$ 39.4	13.8 $\pm$ 13.2	6.9 $\pm$ 4.9

Values are expressed as mean  $\pm$  SD.

together form bouts of activity. These bouts have previously been found to be transient and largely composed of low-intensity walking [2]. The activity pattern characteristics that we report for the school day are remarkably similar to the previous observation studies [2, 3] in terms of the number of bouts per hour, the duration of the rest interval between bouts, and the intensity of bouts. The average physical activity bout length in our study of between 10 and 17 s corresponds well with Bailey et al.'s finding that 95% of children's physical activity bouts last less than 15 s [2]. Previous work using heart rate monitoring has already confirmed that children rarely sustain 10- or 20-minute bouts of moderate-intensity activity [19–21]. More recently, Stone et al. [22] demonstrated that even five-minute bouts of low-intensity activity are infrequent. The data from our study provide further evidence that children's free-living movement patterns are comprised of many, low-intensity, very short-duration bouts.

In contrast to the work of Stone et al. [22], we found that the length and intensity of activity bouts were similar in the lean and obese children, and these showed low intra-individual variation, regardless of location. We found that the intra-individual variance in activity pattern characteristics during school days were generally modest, varying from 9 to 15% in the lean and 8 and 26% in the obese. These are not dissimilar from previous findings of intra-individual variability in composite markers of physical activity, which are reported to be between 20 and 25% in children [9].

Less frequent movement bouts, coupled with longer rest periods, distinguished the obese from the lean. It is noteworthy that the length of time spent resting between bouts of movement shows the greatest intra-individual variation. At the weekend, the frequency of activity bouts declined in both the lean and obese, girls and boys alike. Similarly, the rest interval between movement bouts increased over the weekend in both the lean and obese, but this increase was substantially greater in the obese. This is the first study, to our knowledge, that has reported the variance in the duration of sedentary intervals between bouts of activity in lean and obese children, and our findings suggest that the amount of time spent resting between movement bouts appears to be a key characteristic differentiating lean from obese children. Obese adults have been found to sit for about 2 hours more than the lean [6], and our findings suggest that a similar, albeit less pronounced, difference may exist in lean and obese children. The cross-sectional design of the present study limits the ability to fully understand the relationship between rest intervals and weight status in the young, and experimental or longitudinal work is recommended.

Our findings have implications for the development of interventions. The likelihood of increasing aspects of physical activity that are uncommon in daily movement patterns, such as longer duration bouts of more intense physical activity, is probably poor. Similarly, aspects of physical activity that vary little within an individual are less likely to respond to intervention. Attention may be better

TABLE 4: Intra-individual variation in the activity pattern characteristics at school and at home, by weight status and sex.

		Bouts per day (% CV)	Mean duration of bouts (% CV)	Mean duration of rest intervals (% CV)	Mean peak intensity of bouts (% CV)
School					
Lean ( <i>n</i> = 42)	Boys	14.7 ± 10.7	9.2 ± 5.0	24.9 ± 13.9	9.6 ± 6.8
	Girls	13.4 ± 8.0	10.2 ± 3.8	17.6 ± 8.4*	8.3 ± 3.8
Obese ( <i>n</i> = 42)	Boys	15.5 ± 9.8	11.5 ± 3.9	29.4 ± 19.2	8.4 ± 3.7
	Girls	25.9 ± 18.3	12.3 ± 4.2	23.4 ± 13.8*	11.8 ± 4.2
Home					
Lean ( <i>n</i> = 40)	Boys	37.9 ± 29.4*	16.1 ± 14.3 <sup>#</sup>	52.6 ± 38.3	9.6 ± 5.6 <sup>#</sup>
	Girls	40.6 ± 32.5	23.1 ± 19.2	57.8 ± 34.4*	19.7 ± 15.4*
Obese ( <i>n</i> = 39)	Boys	54.8 ± 31.0*	17.4 ± 11.2 <sup>#</sup>	78.9 ± 43.0	11.0 ± 4.5 <sup>#</sup>
	Girls	49.6 ± 39.0	23.8 ± 16.6	72.8 ± 43.3*	18.4 ± 13.0*

Values are expressed as mean ± SD. CV: coefficient of variation.

\*significant difference between lean and obese,  $P < .05$ ; <sup>#</sup>significant difference between boys and girls,  $P < .05$ .

focused upon decreasing the periods of rest between bouts of movement and increasing the number of short-duration bouts of movement per day.

The primary limitation of this study is the relatively small sample which may increase the chance of type II errors. The data are also restricted to 7–9-year-old Hong Kong Chinese children, and this may limit the generalisability of the findings. It is notable that our primary findings are similar to those of Bailey et al. [2]; however, direct comparisons of our findings to other data sets are challenging because data collection approaches are not uniform. The advent of more sophisticated and affordable monitoring tools, such as triaxial accelerometers with high sampling rates and large memory capacity, will certainly improve this situation and should encourage greater harmonization of accelerometry methodology. We choose not to assess the physical activity patterns at home during the weekday because we felt Hong Kong children were less likely to be active at this time given the homework that is completed during the week; however, these data may provide valuable information about the interplay between movement bouts and inactivity during periods of likely high sedentary behavior and should be considered in future studies.

## 5. Conclusion

To conclude, this study has shown that, similar to previous findings, Chinese children engage in many predominantly low-intensity bouts of short-duration activity. Small lifestyle changes are quite likely to have considerable impact on activity pattern characteristics and identifying the biological and environmental (both physical and sociocultural) antecedents of this pattern of movement is an important next step. The obese child engages in fewer activity bouts and takes longer rest intervals between bouts, both during the school day and at home. As the prevalence of obesity continues to rise, efforts should also be directed toward understanding the consequences of extended rest periods between bouts of movement and fewer movement bouts a day, as well as finding ways to reverse these.

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## Research Article

# A 10-Month Physical Activity Intervention Improves Body Composition in Young Black Boys

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**Objective.** To determine if a 10-month after-school physical activity (PA) intervention could prevent deleterious changes in body composition and cardiovascular (CV) fitness in young black boys. **Methods.** Following baseline measures, 106 boys (8–12 yrs) were randomized to either a control group or an intervention group, further divided into attenders (ATT) and nonattenders (NATT), participating in  $\geq 60\%$  or  $< 60\%$  of the intervention, respectively. The daily intervention consisted of skills development (25 min), vigorous PA (VPA, 35 min), and strengthening/stretching (20 min) components. Body composition was measured by dual-energy X-ray absorptiometry. **Results.** Following the intervention, the ATT exhibited an increase in moderate-to-vigorous PA and a significant reduction in BMI, fat mass, and %BF compared to the control group. A significant association among the intervention energy expenditure and changes in body composition and CV fitness was observed only in the ATT group. **Conclusion.** An after-school PA program of sufficient length and intensity can promote healthy changes in body composition and fitness levels in black boys who attend at least 3 days/week.

## 1. Introduction

The prevalence of childhood obesity has more than tripled over the past three decades. The latest NHANES data (2003–2006) revealed that approximately 35% of 6–11-year-old children are classified as “overweight” or “obese” [1, 2]. This level of obesity in children begets risk factors for cardiovascular disease (CVD) and metabolic diseases. Approximately 25% of obese children have  $\geq 2$  CVD risk factors [3, 4] and more than 45% of newly diagnosed pediatric diabetes cases are classified as “adult-onset” type 2 diabetes [4–7]. This alarming evidence has pushed the prevention of childhood obesity to the forefront of today’s scientific research. This study also reveals that although childhood obesity knows no gender or racial boundary, the rates of obesity are more prevalent in some minority populations. In the 69,000 children (5–17 years) measured across the United States, a significantly higher prevalence of overweight or obesity was reported in black children compared to White, Hispanic- or

other minority children- and boys were reported to have a higher prevalence of obesity compared to girls.

Studies have shown that childhood obesity equates over time to as little as a +2% imbalance between daily energy intake and energy expenditure (EE) [8]. This small positive imbalance can be abated with an increase in regular physical activity (PA). Population-based objective measures of children’s PA levels revealed that only 42% of 6–11-year-old children acquire the recommended 60 min/day of moderate-to-vigorous PA (MVPA); for 12–15-year-old adolescents, this number drops dramatically to  $< 10\%$  [9]. Further, the concomitant increase in the amount of time children spend in sedentary pursuits (e.g., in the classroom, watching television, or playing video games) is independently associated with lower levels of PA and daily PA energy expenditure (PAEE), lower CV fitness, increased risk for obesity, and obesity-related health consequences [10–15]. These associated risks are exacerbated by the reality that obese children have a preference for sedentary behaviors, spend more time

being physically inactive, and may not spend as much energy during PA compared to their nonobese pairs [16–18].

Randomized-controlled intervention studies targeting obese children have successfully increased MVPA participation to enhance body composition and CV fitness [19, 20]. However, healthy developmental changes in body composition (e.g., increased fat-free mass with no change or a decrease in fat mass) and CV fitness (e.g., improved aerobic capacity) have not been demonstrated in studies of children with a wide range of adiposity [21]. These results may be attributed to (1) an insufficient PA dose to correct for energy imbalance in all children, (2) the imprecise measurements of body composition (anthropometric measures) that lack the sensitivity to detect changes in growing children, and (3) the short duration of the training program, limiting the capacity to detect either small decreases in weight gain or the small excessive increases in weight gain associated with childhood obesity [22, 23].

Therefore, we sought to evaluate the efficacy of a 10-month PA intervention on (1) the prevention of excessive age-related increases in body fatness and (2) CV fitness. We hypothesized that black boys who participated in a 10-month after-school PA intervention would prevent excessive age-associated changes in body fatness in addition to a concomitant increase in CV fitness, compared to black boys who did not participate in the 10-month PA program.

## 2. Research Methods and Procedures

**2.1. Participants.** Black boys (8–12 years of age) were recruited from five local elementary schools using study fliers. All 3rd through 5th grade black boys were eligible if they met the following criteria: (1) weigh <300 lbs (equipment limitation), (2) not taking any medications known to affect metabolism, body composition, or fat distribution (e.g., Ritalin or Concerta), and (3) have no known CV, metabolic, or respiratory disease or physical impairment that would limit their participation in regular PA. Twenty-eight percent (300 boys) of the targeted population (1050 boys in 3rd–5th grade) were screened by phone to determine their eligibility to participate in the study. Potential participants and their parent or guardian were invited to attend a group information session where they read and signed the informed consent/assent documents in accordance with the Medical College of Georgia Human Assurance Committee. Participants were given a monetary incentive for the testing portion of the study only; no additional monetary incentive was offered for attending the intervention. Although recruitment was not based on adiposity, the distribution was representative of the higher weight status in the state of Georgia.

Of the 157 boys who consented to be in the study, 122 underwent baseline testing. Although siblings were allowed to participate in the study, only one sibling per family was used in the analyses. Within each family, the sibling with the most data points was selected for analysis. In the case of ties, the sibling with the lowest identification number was selected. The identification numbers were not assigned in any specific order (e.g., oldest sibling first). After removing the siblings ( $n = 4$ ) from the analyses and accounting for those

participants who either (1) were unreachable for baseline or follow-up testing ( $n = 26$ ), (2) declined participation ( $n = 9$ ), (3) became ineligible for participation due to medical reasons ( $n = 8$ ), or (4) were expelled for disciplinary issues ( $n = 4$ ), 106 boys were included in the analyses.

**2.2. Baseline and Follow-Up Testing.** Participants reported to the Georgia Prevention Institute of the Medical College of Georgia for testing prior to the beginning of the study and again after 10 months. Baseline testing began during the summer months before schools started and continued until mid-fall with as many as three boys tested on any given day. The boys were integrated into the intervention on a rolling basis with each subject given the opportunity to participate in at least 10 months of the intervention. Follow-up testing for the intervention group was conducted within 1–3 days following the last day of the 10-month intervention. All testing was conducted by trained study personnel with an exercise physiology or related background.

**2.3. Sexual Maturation Assessment.** Pubertal status was assessed by study pediatricians based on the criteria established by Marshall and Tanner [24, 25]. Utilizing gonad and pubic hair development separately, the subject was then classified as immature (Tanner 1-2), peripubertal (Tanner 3-4), or mature (Tanner 5) for the analyses. Examination of the Tanner staging for pubic hair and gonad development was not refused by any of the boys.

**2.4. Body Size and Composition Assessment.** Height, to the nearest 0.1 cm, and weight, to the nearest 0.1 kg, were measured by standard methods using a wall-mounted stadiometer (Healthometer) and floor scale (Dectecto), respectively. Body mass index (BMI) was calculated as  $\text{weight}(\text{kg})/\text{height}(\text{m}^2)$ , and BMI percentile (BMI%) was obtained from the Centers for Disease Control age- and gender-specific growth charts [26]. Waist circumference was measured along the narrowest width between the rib cage and the umbilicus.

Total body composition was measured in a 3-compartment model as total fat mass (FM), fat-free mass (FFM), and bone mineral content (BMC) using dual-energy X-ray absorptiometry (DXA; Hologic QDR-1000, Waltham, MA). The boys were measured in a supine position while wearing light clothing with no metal and no shoes or jewelry. Bone mineral density and %BF were derived from the three aforementioned components using the DXA scanner software (Hologic, version 2.3.1).

**2.5. Cardiovascular Fitness Assessment.** Cardiovascular fitness ( $\text{VO}_2$  max) was assessed by the method of indirect calorimetry (Sensormedics Vmax 229 cardiopulmonary system, Yorba Linda, CA) using a multistage treadmill test. The treadmill protocol began with a 4-min warm-up at 2 mph and 0% grade. The speed was then increased 0.5 mph every 2 minutes to 3.0 mph followed by 2%–3% grade increases every 2 minutes until reaching 20% grade (maximum grade of the treadmill) or until voluntary exhaustion. Participants were

asked to rate their perceived exertion using the 6–20 point Borg scale. Participants were considered to have attained  $\text{VO}_2$  max if they met two of the following three criteria: (1) an increase in heart rate (HR)  $<5$  bpm between the final two workloads, (2) an increase in oxygen consumption ( $\text{VO}_2$ )  $<100$  ml/min between the final two workloads and (3) a respiratory exchange ratio  $>1.10$ . Although all participants were encouraged verbally to give a maximal effort, approximately half of them stopped the test voluntarily before reaching  $\text{VO}_2$  max. In addition, only about half of the boys who attained  $\text{VO}_2$  max at baseline also did so at followup. Because the achievement of maximal effort is not common in participants of this age [27], an alternate index of CV fitness was used:  $\text{VO}_2$  at an HR of 170 bpm ( $\text{VO}_2$ -170).  $\text{VO}_2$ -170 was determined from individual regression analyses of the  $\text{VO}_2$  and HR responses to all completed workloads during the treadmill test. Heart rate was monitored throughout the test using a Polar HR monitor (Polar USA, Lake Success, NY).

**2.6. Physical Activity Assessment.** Free-living PA was measured using a seven-day PA recall [28]. The boys were questioned about their activities, including sleep, over the seven days prior to the interview, starting with the previous day and working backwards. Thus, the seven-day recall included the PA associated with the PA program for the boys in the intervention group at followup. This interview, typically completed in 20–30 minutes, was conducted by trained study personnel. Values of hard PA (identified as PA that caused increased breathing and moderate movement including activities such as, dancing, aerobics, and soccer) and very hard PA (identified as PA that caused hard breathing and quick movements including activities such as, tennis, cycling, and running) were summed to derive an index of vigorous PA (VPA). MVPA was calculated as the sum of VPA and moderate PA (identified as PA that caused normal breathing and some movement including activities such as, walking briskly, volleyball, gymnastics, and gardening).

**2.7. After-School Intervention.** Following baseline testing, participants were randomized into either the intervention group ( $n = 62$ ) or the control group ( $n = 44$ ) with a ratio of three to two, respectively. In the instance of siblings, the first to be tested was randomized and the remaining sibling(s) was/were placed in the same group. Participants in the control group received no intervention and were not allowed to stay for the after-school intervention but rather instructed not to change their daily after-school routine. Participants in the intervention group stayed at their school at the end of each full school day ( $177 \pm 8.6$  days) to receive a 2-hour intervention over a 10-month period, excluding school holidays. The after-school PA intervention is described in detail elsewhere [29]. Briefly, the intervention was conducted by trained study personnel with exercise-related education plus 1-2 trained classroom teachers. The program consisted of 30 minutes of homework time during which the boys were provided with a healthy snack followed by 80 minutes of PA. All the snacks were individually packaged and every day the boys had a choice of something salty (e.g., crackers and

cheese), something sweet (e.g., low-fat cookies), or a fruit or vegetable. The PA program included 25 minutes of skills development (e.g., how to dribble a basketball), 35 minutes of VPA, and 20 minutes of toning and stretching with 5 minutes rest between each component. Throughout the intervention, the boys wore a Polar S610 HR monitor (Lake Success, NY) to record their PA intensity and to estimate their EE during the sessions. During the VPA component, the boys were asked to maintain an HR of at least 150 bpm. Activities during the VPA component included games such as, basketball, tag, softball, and relay races, all of which were modified to keep all the boys sufficiently active ( $\geq 150$  bpm) throughout the 35-minute period.

**2.8. Statistical Analyses.** For analyses, the intervention group was subdivided into boys who either attended  $\geq 60\%$  of the intervention (attenders, ATT;  $n = 31$ ) or those who did not attend at least 60% of the intervention (nonattenders, NATT;  $n = 31$ ). Group comparisons of baseline and follow-up values for all outcome variables (body composition, CV fitness, and PA variables) were conducted using a  $3 \times 2$  repeated measures ANOVA using group (ATT, NATT, and Control) and test session (baseline and followup) as main effects. The relationships at baseline and for the change scores among the outcome variables were determined using Pearson correlation analyses. Within the intervention group, the relationships among the outcome variables, program attendance, and HR during the aerobic portion of the program were all assessed using Pearson correlation analysis. Statistical significance was set at  $\alpha = 0.05$ .

### 3. Results

**3.1. Participant Characteristics.** One hundred and six 3rd–5th grade boys participated in the study and were randomized into either the intervention ( $n = 62$ ) or the control ( $n = 44$ ) group. All of the boys were classified as prepubertal for gonad and pubic hair development. The descriptive data for baseline measures are presented in Table 1. There were no significant differences at baseline among the control group, ATT ( $n = 31$ ), and NATT ( $n = 31$ ) for all outcome variables.

**3.2. Program Evaluation.** All children in the intervention group participated in a minimum of 10 months of PA for the study. The average attendance for the intervention group was  $57.7 \pm 3.1\%$ , which varied greatly between the ATT ( $82.9 \pm 1.8\%$ ) and NATT ( $32.8 \pm 4.5\%$ ). Heart rate during the VPA component of the daily intervention was not significantly different between ATT and NATT boys and averaged  $162.0 \pm 1.4$  bpm. Additionally, no significant differences in total EE per session between the ATT and NATT boys were observed. The average EE during the 80-minute sessions was  $369.8 \pm 21.4$  kcal/session, of which  $192.3 \pm 10.8$  kcal/session was expended during the VPA component alone.

**3.3. CV Fitness.** The baseline and follow-up measures of CV fitness include  $\text{VO}_2$ -170 expressed both in absolute terms (L/min) and relative to body mass (ml/kg/min) (Table 2).

TABLE 1: Baseline Participant Characteristics (Means  $\pm$  SE).

	ATT (n = 31)	NATT (n = 31)	Controls (n = 44)
Age (y)	9.7 (0.2)	9.8 (0.2)	9.9 (0.2)
BMI Classification			
Overweight/Obese (%)	48.4	48.4	45.5
Sexual Maturity			
Pubic	1.45 (0.11)	1.32 (0.10)	1.27 (0.09)
Organ	1.26 (0.12)	1.13 (0.06)	1.36 (0.11)
Height (cm)	143.2 (1.7)	141.0 (1.8)	140.9 (1.2)
Weight (kg)	43.0 (2.9)	41.6 (2.8)	40.1 (1.7)
Resting Vitals			
Systolic BP (mm Hg)	105.5 (9.5)	103.4 (9.8)	101.8 (7.2)
Diastolic BP (mm Hg)	59.9 (6.4)	57.6 (6.3)	57.6 (6.1)
HR (bpm)	71.8 (9.1)	76.3 (12.1)	74.0 (9.1)
Peak Vitals			
HRpk (bpm)	187 (3.3)	188 (2.4)	190 (2.1)
VO <sub>2</sub> pka (L/min)	1.3 (0.07)	1.1 (0.06)	1.2 (0.04)
VO <sub>2</sub> pkr (ml/kg/min)	30.5 (7.8)	28.3 (6.2)	30.2 (6.6)

ATT = >60% attendance; NATT = <60% attendance; BP = blood pressure; HR = heart rate; HRpk = peak heart rate; VO<sub>2</sub>pka = peak oxygen consumption in absolute terms; VO<sub>2</sub>pkr = peak oxygen consumption relative to body mass.

TABLE 2: Body Composition, CV Fitness and PA measures by Group (Means  $\pm$  SE).

	Baseline			Follow-up		
	ATT (n = 31)	NATT (n = 31)	CON (n = 44)	ATT (n = 31)	NATT (n = 31)	CON (n = 44)
BMI (kg/m <sup>2</sup> )	20.4 (5.4)	20.3 (4.9)	20.0 (4.4) <sup>c</sup>	20.3 (5.5)	20.7 (5.2)	20.5 (4.6) <sup>c</sup>
Waist circ. (cm)	66.4 (11.6)	66.1 (10.8)	65.7 (9.9)	66.9 (12.1)	67.5 (12.2)	67.1 (10.3)
FM (kg)	11.6 (9.3)	12.1 (8.8)	10.5 (6.8) <sup>c</sup>	11.3 (9.9)	12.6 (9.5)	11.4 (7.7) <sup>c</sup>
FFM (kg)	30.8 (7.6) <sup>a</sup>	29.2 (7.3) <sup>b</sup>	29.1 (5.2) <sup>c</sup>	34.1 (9.0) <sup>a</sup>	32.7 (9.0) <sup>b</sup>	32.6 (6.9) <sup>c</sup>
%BF	24.4 (9.5) <sup>a</sup>	26.4 (9.3) <sup>b</sup>	24.5 (9.7)	22.1 (9.5) <sup>a</sup>	25.0 (9.4) <sup>b</sup>	23.9 (10.4)
BMC (kg)	1.28 (3.27) <sup>a</sup>	1.22 (2.92) <sup>b</sup>	1.20 (2.24) <sup>c</sup>	1.45 (4.06) <sup>a</sup>	1.40 (4.27) <sup>b</sup>	1.36 (2.98) <sup>c</sup>
BMD (g/cm <sup>2</sup> )	0.89 (0.07) <sup>a</sup>	0.89 (0.06) <sup>b</sup>	0.89 (0.06) <sup>c</sup>	0.94 (0.08) <sup>a</sup>	0.94 (0.13) <sup>b</sup>	0.92 (0.06) <sup>c</sup>
VO <sub>2</sub> -170 (ml/kg/min)	25.5 (8.0)	22.6 (5.6)	23.4 (3.8) <sup>c</sup>	26.8 (5.9)	24.3 (5.4)	25.9 (5.9) <sup>c</sup>
VO <sub>2</sub> -170 (L/min)	1.02 (0.28) <sup>a</sup>	0.90 (0.25) <sup>b</sup>	0.91 (0.16) <sup>c</sup>	1.18 (0.35) <sup>a</sup>	1.06 (0.32) <sup>b</sup>	1.10 (0.22) <sup>c</sup>
	(n = 27)	(n = 22)	(n = 36)	(n = 28)	(n = 23)	(n = 36)
MVPA (hrs/day)	0.91 (0.14) <sup>a</sup>	0.83 (0.13)	0.83 (0.10)	1.49 (0.12) <sup>a</sup>	0.98 (0.13)	0.91 (0.12)

PA = physical activity; SE = standard error; ATT = boys in the intervention group who attended  $\geq$  60%; NATT = intervention boys who attended < 60%; CON = control; BMI = body mass index; circ. = circumference; FM = fat mass; FFM = fat free mass; %BF = percent body fat; BMC = bone mineral content; BMD = bone mineral density; VO<sub>2</sub>-170 = the VO<sub>2</sub> at a heart rate of 170 bpm during the graded treadmill test; MVPA = moderate-to-vigorous PA. Significant difference between baseline and follow-up for <sup>a</sup>ATT, <sup>b</sup>NATT, and <sup>c</sup>CON groups.

There was a similar improvement in VO<sub>2</sub>-170 across all three groups from baseline to followup when expressed in L/min ( $P < .001$ ). However, the control group demonstrated the only significant increase in VO<sub>2</sub>-170 when expressed in ml/kg/min ( $P < .0001$ ). Within the ATT group alone, there was a positive relationship between the EE during the VPA component of the intervention and changes in VO<sub>2</sub>-170 expressed as L/min ( $r = 0.56$ ;  $P = .0018$ ) and when expressed as ml/kg/min ( $r = 0.47$ ;  $P = .012$ ). Additionally, a negative relationship was observed between the VPA component EE

and the decrease in %BF ( $r = -0.43$ ;  $P = .02$ ). Interestingly, no relationships were observed between either the percent attendance or the average HR maintained during the VPA component of the intervention sessions and the changes in body composition or CV fitness measures in either the ATT or NATT.

**3.4. Physical Activity.** At baseline, the amount of MVPA reported by the boys was similar among the control, NATT, and ATT groups. Additionally, no relationships among

TABLE 3: Relationships between Body Composition, CV Fitness and Physical Activity levels at Baseline and Follow-up. (Pearson correlation coefficients).

	Time	Body Composition				
		BF (%)	BMI (kg/m <sup>2</sup> )	FM (kg)	FFM (kg)	MVPA (hrs/day)
VO <sub>2</sub> -170 (ml/kg/min)	BL	<b>-0.64</b>	<b>-0.63</b>	<b>0.64</b>	<b>-0.48</b>	0.01
	FU	<b>-0.76</b>	<b>-0.67</b>	<b>0.71</b>	<b>-0.32</b>	0.22
MVPA(hrs/day)	BL	0.20	0.22	0.24	0.22	—
	FU	-0.18	-0.08	-0.1	0.06	—

VO<sub>2</sub>-170 = the VO<sub>2</sub> at a heart rate of 170 bpm during the graded treadmill test; BF = body fat; BMI = body mass index; FM = fat mass; FFM = fat free mass; MVPA = moderate-to-vigorous physical activity; BL = baseline; FU = follow-up; **Bold italic** font indicates a significant relationship ( $p < .05$ ).

MVPA and measures of CV fitness and body composition were observed. At followup, the ATT reported a significant increase ( $P = .04$ ) in MVPA by 34.8 min/day; however, no change in MVPA for the control group or the NATT group was reported (Figure 1). There were no significant relationships between the change in reported MVPA and changes in BMI ( $r = -0.08$ ;  $P = .44$ ), %BF ( $r = -0.12$ ;  $P = .26$ ), and VO<sub>2</sub>-170 ( $r = -0.03$ ;  $P = .73$ ) among all three groups.

**3.5. Body Size and Composition.** There was a negative relationship among CV fitness and body composition measures at baseline for the entire population sample and these relationships were stronger at followup (Table 3). A significant group  $\times$  time interaction was observed for %BF (Figure 2(a)), such that both the ATT ( $P < .0001$ ) and NATT ( $P = .019$ ) groups exhibited a decrease in %BF, whereas no significant change was observed in the control group ( $P = .18$ ). Additionally, the decrease in %BF among the boys in the ATT group was significantly greater than the change in the control group ( $P = .029$ ). A group by time interaction for BMI was also observed (Figure 2(b)) following the 10-month program, such that the control group exhibited a significant increase in BMI ( $P = .0034$ ), whereas no change was observed in the NATT group ( $P = .06$ ) or the ATT group ( $P = .33$ ). The change in BMI in the ATT group, a slight decrease, was significantly different than the change in both the NATT group ( $P = .046$ ) and the control group ( $P = .009$ ). Further, a similar group by time interaction was observed for changes in FM (Figure 2(c)). Finally, the changes in FFM ( $P = .91$ ) and BMD ( $P = .91$ ) and BMC ( $P = .85$ ) over the 10 months were similar across all groups.

#### 4. Discussion

The main finding of this study is that 10 months of after-school PA can prevent further accretion of undesirable levels of adipose tissue in black boys of varying adiposity levels. The boys who attended the intervention at least 3 days/week had a significant reduction in body fat, BMI, and fat mass compared to significant increases in BMI and fat mass observed in the control group. Although there were similar increases in FFM between the control and ATT groups, these

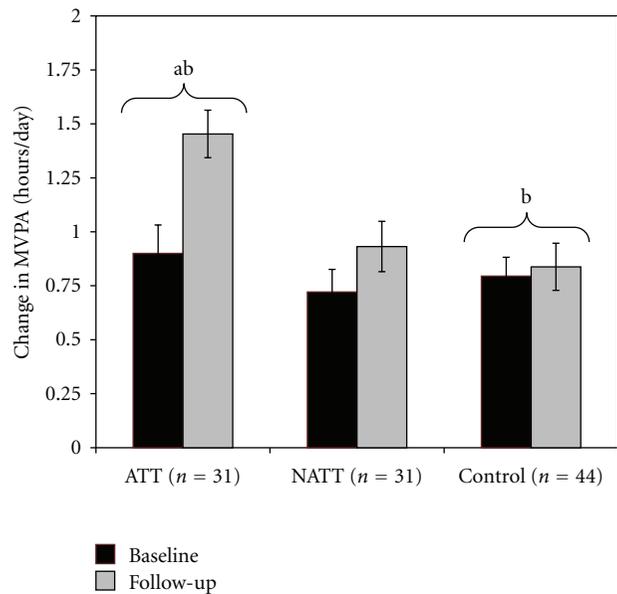


FIGURE 1: Baseline (black bars) and follow-up (grey bars) measures of MVPA by group. Values are means  $\pm$  SE. (a) Significant difference from baseline to follow-up measures; (b) change from baseline to followup is significantly different between ATT and Control groups.

findings indicated a beneficial effect of physical activity on overall body composition in young black boys.

A unique aspect of the present study included the statistical power to divide the PA intervention group and compare attenders versus nonattenders, those boys who attended at least 60% (ATT) and those who did not (NATT), respectively. This comparison lends support to the beneficial response of PA on body composition, only if consistency is maintained. Attenders exhibited a significant decrease in %BF of  $-2.25 \pm 0.57\%$  compared to a decrease of only  $-0.63 \pm 0.44\%$  in the control group over the 10-month PA intervention. Although the boys who did not attend at least 60% of the intervention gained less FM than the control group, the increase in BMI over the 10 months was similar to the control group. Consequently, this resulted in a similar and nonsignificant decrease in %BF in the NATT and control groups. Interestingly, this change in body composition was

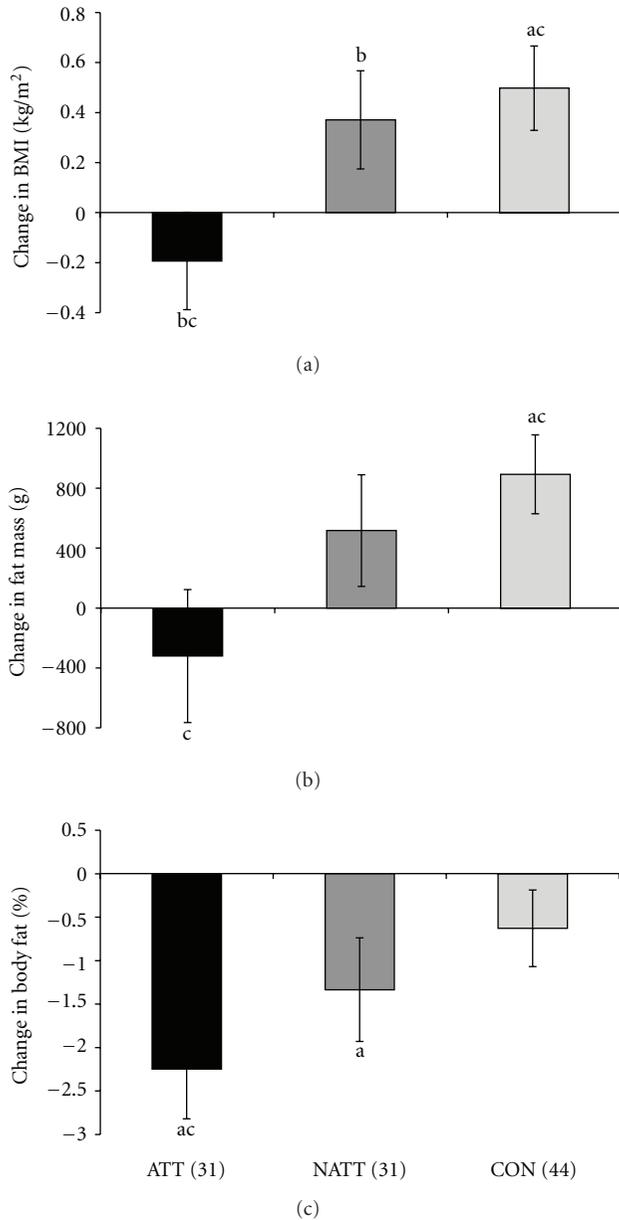


FIGURE 2: Baseline and follow-up measures of (a) BMI ( $\text{kg}/\text{m}^2$ ), (b) fat mass (g), and (c) body fat (%) for the ATT group (black bars), NATT group (dark grey bars), and Control group (light grey bars). Values are means  $\pm$  SE. (a) Significant difference from baseline to followup; (b) change from baseline to followup is significantly different between ATT and NATT groups; (c) change from baseline to followup is significantly different between ATT and Control groups.

independent of changes in FFM because all three groups had similar increases in FFM. Moreover, there were similar changes in BMC, BMD, and FFM across all three groups of boys which indicates that although there was an increase in reported MVPA in the ATT group compared to the control group, this increase in EE associated with participation in the intervention did not hinder increases of lean tissues related to normal growth patterns over the 10 months [30].

The results of this intervention are comparable, but less dramatic, to another study conducted in our laboratory with young black girls using a similar after-school intervention [29]. The success of these PA interventions, compared to less successful interventions [21], is, in part, attributed to the exercise dose (duration and intensity) provided by the program. The average daily energy cost of the program ( $370 \pm 21$  kcal/session) is more than twice the magnitude of the proposed energy surplus associated with childhood obesity (100–165 kcal/day) [23, 31]. It is speculated that small increases in total daily EE over time will abate the excessive increases in body mass associated with obesity. This is supported by the fact that only the boys who attended the intervention program on a regular basis reduced their adiposity levels over the 10 months, whereas the boys in the control or NATT groups both exhibited an increase in FM over the same time period. Although small, there was a positive change in BMI as a result of attending the program. If these positive changes are compared to the CDC's age- and gender-specific growth charts, this small reduction or prevention of increasing BMI may have significant physiological and health implications. For example, at age 8, a child with a BMI of  $21 \text{ kg}/\text{m}^2$  is classified as obese according to these standardized charts. A year later, if that same child increased his BMI by the amount observed in our control group ( $0.5 \text{ kg}/\text{m}^2$ ), he would continue to be classified as obese by age 9. Instead, if that same child a year later slightly reduced his BMI as seen in our ATT group ( $-0.2 \text{ kg}/\text{m}^2$ ), he would be classified as overweight rather than obese by age 9. If this trend was to continue, by age 12, that child who participated in regular PA similar to our intervention would have a BMI of  $20.2 \text{ kg}/\text{m}^2$  and would be classified as a healthy weight, thus reducing his potential risk for obesity-related diseases. Although these findings are promising, with half of the participants in the intervention group not acquiring the desired PA dose (<60% attendance), it is unclear if this program is generalizable across populations.

In the current study, the children were asked to play at a vigorous intensity by maintaining an HR of at least 150 bpm during the 35-minute VPA component of the intervention. Using a standardized maximal HR (HR<sub>max</sub>) of 200 bpm for children, the average HR achieved during the intervention (162 bpm) was 81% of predicted HR<sub>max</sub>, which is classified as vigorous intensity PA (70%–89% HR<sub>max</sub>) [32]. Recent studies along with data from our laboratory suggest that VPA might have a favorable impact on body composition which is to some degree independent of EE [14, 33]. The energy cost of the present intervention was derived from individual linear regressions developed from the HR and  $\text{VO}_2$  responses during the graded treadmill tests. In support, the results suggest that the EE was sufficient to abate deleterious changes in body composition and improvements in CV fitness [29]. Additionally, these results are consistent with descriptive studies indicating that accelerometry-measured VPA is strongly related to lower levels of fatness and better fitness than moderate PA (MPA). In the current study, there were no relationships between the measure of exercise intensity (HR during the VPA component) and either body composition or CV fitness; however, there was a weak

relationship between these same factors and the EE during the VPA component.

Although the intervention promoted healthy changes in body composition, the intervention had little impact on CV fitness. The improvements in absolute measures of CV fitness (L/min) were similar across all three groups; however, in contrast to our hypothesis, when expressed relative to body mass, the control group had the greatest increase in CV fitness (9.8%) compared to both the ATT group (5.5%) and the NATT group (5.3%). Although we cannot explain this increase, the effort of the control group during follow-up exercise testing may have been greater than baseline testing. In support of similar postintervention CV fitness changes, a recent review of the literature revealed that endurance training at a frequency of 1 to 5 days/week, 20 to 60 min/session, at an intensity of 70% to 90% of maximal HR is necessary for improving CV fitness from 5% to 15% [34]. However, the most common activities in these studies involved more endurance training, steadystate-type activities (e.g., aerobics, running, cycling, etc.) rather than common children's games (e.g., nonsteady-state games) employed in the current intervention. The review further states that boys needed at least 60 min/day of MVPA to promote higher CV fitness. This suggests that the current intervention, although sufficient to counterbalance the energy surplus of obesity, was not sufficient in intensity and/or duration per session to enhance CV fitness in young boys.

The implementation of this intervention study and its choice of some outcome measures, to our knowledge, have never been implemented and add to the strength of the present findings. The length of the program allowed for revealing the impact of small daily changes in MPA and VPA on body composition as children go through the growth process. The magnitude of the sample size, focusing only on a single gender and race, allowed for the power to emphasize the changes in a population that is at higher risk for obesity and obesity-related diseases. Finally the sensitivity of some of the outcome measures, specifically the DXA, allowed for the detection of small but significant changes in body composition that would not be detected via other measures (e.g., skinfolds) [35, 36]. The levels of PA participation in this study exceed the PA dose recommended in the most recent PA guidelines published by the U.S. Department of Health and Human Services (60 min/day of MVPA of which VPA should be included at least 3 days/week) [37]. However, using self-report assessments in the form of questionnaires have demonstrated low-to-moderate validity for assessing PA levels in children [38]. In the current study, the increase in MVPA in the ATT group at followup may be attributed to the regularity of the after-school program and the investigators cues about whether or not the subject participated in the program during the administration of the recall at followup. Objective monitoring of MVPA is warranted to assess changes in MVPA in future intervention studies.

In conclusion, young black boys who attended the 10-month after-school PA intervention at least 3 days/week exhibited healthy weight management compared to both the boys who did not attend the intervention and the control

group. Although there were no relationships between the changes in MVPA and body composition, the postintervention decrease in BMI and %BF observed in the ATT may be indicative of an improved energy balance over the 10 months. These findings implicate the importance of engaging in physical activity at least 3 days per week to prevent age-associated increases in BMI, FM, and body fat and reduce the risk of childhood obesity. Research should continue in this area, using more objective means of assessing changes in PA participation and assessing program intensity to determine the impact of such a program on total daily energy expenditure.

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## Research Article

# SALSA : Saving Lives Staying Active to Promote Physical Activity and Healthy Eating

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Physical inactivity, poor dietary habits, and obesity are vexing problems among minorities. SAVING Lives, Staying Active (SALSA) was an 8-week randomized controlled crossover design, pilot study to promote regular physical activity (PA) and fruit and vegetable (FV) consumption as a means to preventing weight gain among women of color. Participants completed measures of demographics, PA, and dietary habits. Women ( $N = 50$ ;  $M = 42$  years) who participated were overweight ( $M$  BMI = 29.7 kg/m<sup>2</sup>;  $M$  body fat = 38.5%) and reported low levels of leisure time PA ( $M = 10.7$  MET-min/wk) and FV consumption ( $M = 4.2$  servings/day). All were randomized to a four-week (1) semiweekly Latin dance group or (2) internet-based dietary education group. All participants reported a significant increase in weekly leisure time PA from baseline ( $M = 10.7$  MET-min/wk) to follow up ( $M = 34.0$  MET-min/wk,  $P < .001$ ), and FV consumption increased over time by group ( $P = .02$ ). Data suggest that Latin dance interventions to improve PA and web-based interventions to improve dietary habits show promise for improving health among women of color.

## 1. Introduction

Populations of color are among the fastest growing subpopulations in the USA [1] and are at great risk for physical inactivity, poor dietary habits, and obesity [2–4]. Recent estimates suggest that one-third of African American and Hispanic adults are physically inactive and fewer than one-fourth meet the recommendations for fruit and vegetable consumption [5, 6]. In addition to high rates of physical inactivity [7], ethnic minority women are at the greatest risk for not maintaining regular physical activity and weight gain [2–4]. Innovative and sustainable strategies to increase and maintain physical activity and prevent weight gain are needed in this population that provide measurable health benefits and improved quality of life [8, 9].

Latin dance interventions show promise for increasing physical activity duration and intensity and are seen as

intrinsically enjoyable, potentially more easily adopted and maintained than traditional exercise programs [10]. The Latino culture and population continue to grow in the USA, and Latin dancing is a widely accepted and popular in many population subgroups, even beyond the Latino community. Prior research has shown that Latin dancing meets moderate to vigorous intensity requirements, sufficient to meet weight loss and maintenance recommendations [11]. Prior studies have also demonstrated that interventions which involve community and culturally relevant interventions are more successful and sustainable than those which do not incorporate these factors [12].

The use of computer and internet technology has also been increasing in popularity as the graphical interface has made the Internet easy and appealing. As is the case with Latin dance, web-based interventions to improve physical activity and dietary habits can be made culturally relevant

and engaging to a diverse audience. Evidence suggests that most women of color have access to computers and the internet at home or work and access health information online [13]. One study recently found that as many as one out of every five internet searches done by African American and Hispanic or Latina women was for health information [14]. Previous studies have shown that internet-based studies increase reach and accessibility and are effective for changing diet and physical activity behaviors [13, 15–17].

Although previous studies have explored the use of Latin dance and internet technologies to increase physical activity and improve dietary habits [11, 15, 18, 19], there have not been any studies that have combined the two methods to improve health habits that may reduce weight gain in women of color. Health promotion interventions improve physical activity and dietary habits, but often face retention challenges leading to low adherence [20]. Findings show that minority women do increase their physical activity in response to interventions [21, 22]. However, the changes in physical activity are often modest and inconsistent, suggesting a need for studies that increase adherence and accessibility and engage women of color [21, 23, 24].

The SAVING Lives, Staying Active (SALSA) study was a pilot study to promote regular physical activity and fruit and vegetable consumption among women of color. The aims of the study were to (1) determine how willing women of color were to participate in an internet-based intervention; (2) determine whether a Latin dance intervention was sufficient to promote increase in weekly physical activity in women of color; (3) to determine whether an internet intervention was sufficient to promote increases in fruit and vegetable consumption. We hypothesized that Latin dancing would provide adequate intensity to reach moderate or greater intensity physical activity and that women would increase their fruit and vegetable consumption as a result of participating in the web-based arm of the study.

## 2. Materials and Methods

**2.1. Participants.** Participants were recruited via distributed brochures, word of mouth, and local electronic newsletters. Interested women were invited to visit the SALSA study website and register online. Ninety-five women registered online and completed a short screener questionnaire determining the following inclusion criteria: self-identified woman of color, between the ages of 25 and 60 years old, able to do physical activity without medical supervision as measured by the Physical Activity Readiness Questionnaire (PAR-Q) [25], willing to be randomized, and had access to a computer with internet at least 5 days per week. Of those screened ( $N = 95$ ), eligible women ( $N = 71$ ) were invited to participate in a baseline health assessment and enroll in the study. Fifty women of color completed the baseline health assessment and were enrolled in the study, yielding a recruitment ratio of 53%, suggesting that in online recruitment, about double the number of participants must be screened to achieve the desired enrollment. The study was approved by the University of Houston Committee for the Protection

of Human Subjects and all participants provided written informed consent.

**2.2. Assessments.** Women who completed the T1 assessment were given a link to the online survey. Women who completed the T1 assessment and online survey ( $N = 50$ ) were enrolled in the study. After four weeks of intervention, women completed a cross-over (T2) health assessment. Women who completed the T2 assessment and online survey were eligible to switch groups. Women who were previously in the internet-based comparison switched to the Latin dance group and vice versa. After an additional four weeks of intervention, women completed a postintervention (T3) assessment and online survey and returned to the University after four more weeks for a follow-up (T4) assessment.

**2.3. Anthropometry and Body Composition.** Body mass index (BMI =  $\text{kg}/\text{m}^2$ ) and percent body fat were collected at all health assessments by trained personnel using established protocols [26]. Height was measured using a portable stadiometer. Body weight and body fat percentage were measured using a Tanita TBF-310 body composition analyzer (Tanita Corporation of America, Inc., Arlington Heights, IL, USA) [27, 28]. Participants were measured twice, and an average of the two measurements was used in analyses.

**2.4. Physical Activity.** Self-reported weekly leisure-time physical activity was measured at all time points using the validated Godin Leisure-Time Exercise Questionnaire [29]. The questionnaire asked participants to report how much and often they did all types of physical activity during a 7-day period and is then transformed into weekly metabolic units of physical activity.

As an objective measure of physical activity during Latin dancing, women wore a unidirectional ActiGraph GT1M accelerometer (ActiGraph, LLC, Pensacola, FL, USA) during Latin dance sessions [30]. The ActiGraph accelerometer has exhibited strong associations between activity counts and measured energy expenditure, was clearly responsive to different intensities of physical activity, and had the lowest amount of variance across monitors, indicating strong validity and overall reliability [31]. Accelerometer data were collected as counts per 10 second epochs, the smallest epoch setting for this accelerometer [32]. This epoch setting was chosen to be the closest to the heart rate monitor measurement intervals and has not been shown to have an effect on moderate physical activity [33, 34]. Although a 5-second epoch would have been ideal to measure vigorous or very vigorous physical activity [34], this setting was not available. A 10-second epoch is more ideal than a 60-second epoch length for measuring moderate or greater intensity physical activity [33]. Counts were translated into minutes spent in moderate or greater physical activity per session using an established cutpoint as described by Layne and his colleagues [35], and an average number of minutes per session over the course of the study were used in analyses.

As a measure of heart rate during Latin dancing, women wore Polar E600 heart rate monitors (Polar Electro Inc., Lake

Success, NY, USA) during Latin dance sessions. Heart rate monitors was programmed with each participant's age and limits of their target heart rate zone (60 to 85% of their maximum heart rate based on participant's age). Heart rate was measured every 5 seconds. Average heart rate and average time spent in one's target zone over the course of the study was used in analyses.

**2.5. Dietary Habits.** Fruit and vegetable and fat consumption were measured using the National Cancer Institute's Fruit and Vegetable and Fat Screeners, respectively, to measure number of servings consumed and total calories consumed from fats [36, 37]. Fruit and vegetable consumption was reported in terms of frequency and amount consumed each time over the last month. The Fruit and Vegetable Screener has shown adequate validity in adult women [38]. The Fat Screener measures usual dietary intake of percent calories from fat. Fat intake was reported in terms of frequency over the last 12 months. The Fat Screener has shown good validity in adult women [39].

**2.6. Website Use.** SALSA website use was monitored throughout the study. Number of visits per day, total number of visits during the four-week access period and duration spent on the website were recorded by participant ID.

**2.7. Intervention.** Participants were randomized to one of two groups, (1) a biweekly Latin dance group ( $N = 25$ ) or (2) an internet-based dietary education comparison ( $N = 25$ ), using a computer generated, weighted, randomization procedure; investigators and participants were blind to intervention condition during the randomization procedure. The flow of the study is presented in Table 1.

Women in the Latin dance group attended eight one-hour Latin dance lessons, where they learned four basic Latin dance steps (salsa, merengue, bachata and cha cha) taught by a professional dance instructor who instructed the group together to music. Each session consisted of a review of the basic steps, variations on the steps, and a dance incorporating the steps. At the end of the session, the instructor spent between five and ten minutes doing a cool down, consisting of slow dance steps, stretching and guided breathing. Throughout class, the instructor worked with the group as a whole and gave pointers to individuals as needed.

The informational and interactive website delivered content on dietary habits based on the salsa food theme. The SALSA website provided information on improving dietary habits by increasing fruit and vegetable consumption for four weeks. All intervention materials were produced at an eighth grade reading level, ensuring women with varying socioeconomic backgrounds were able to participate. To encourage participants to visit at least once per week the website was updated weekly with new educational content and tools, such as information about food safety, storage times, seasonality, serving sizes, and daily recommendations. Participants were e-mailed weekly when new content was posted. In addition to educational content, one salsa recipe and two recipes using fruit and vegetables were provided

each week. Participants were given a log-in username and password, and they could access the website freely for four weeks while in the internet-based dietary education group. At their first log-in, they were instructed to update their profile and change their password. In order to avoid contamination between groups, only content on dietary habits and fruit and vegetable consumption was provided on the website and content on adopting physical activity and safety was provided only at Latin dance sessions. Access to the website was not available to women while they were completing the Latin dance intervention.

**2.8. Statistical Analysis.** Prior to analysis, normality was checked for all variables; the fruit and vegetable consumption variable was transformed using a natural log transformation to create a symmetric distribution. Differences in these measures between groups at baseline were evaluated using independent samples *t*-tests. Simple changes in the outcome measures over time were evaluated using paired *t*-tests and repeated measures analyses. Covariates, such as age, income, education, dance session attendance and website visits, significantly correlated with physical activity, dietary habits and BMI were controlled for in analyses. Means, standard deviations, frequencies, and *t*, *F*, and *P* values for each test are reported below.

### 3. Results

**3.1. Descriptives.** Women ( $N = 50$ ) were middle aged ( $M = 41.0$  years,  $SD = 9.6$ ) and overweight ( $M$  BMI =  $29.7$  kg/m<sup>2</sup>,  $SD = 5.3$ ;  $M$  body fat =  $38.5\%$ ,  $SD = 7.0$ ). Most women (74.0%) were college graduates and reported a mean household income of approximately \$90,000 for a family of four, suggesting a relatively high socioeconomic status. Means and standard deviations for body composition, physical activity, dietary habits, and psychosocial variables by group and time point are presented in Table 2.

**3.2. Attendance and Website Usage.** Women who participated in the dance group first (Group 1) attended 5 out of 8 dance sessions ( $M = 4.96$  sessions,  $SD = 2.6$ ), and women randomized to the dance group second (Group 2) attended 4 out of 7 dance sessions ( $M = 3.6$ ,  $SD = 2.0$ ; one session cancelled due to Hurricane Ike).

Participants visited the SALSA educational website at least once but no more than 10 times ( $M = 2.98$ ,  $SD = 2.22$ ) during the four weeks they had access to the site while participating in the internet-based dietary education group. Time spent on the site varied by date and visit number. If it was their first time visiting the site, women spent roughly 16 minutes ( $M = 16.1$ ,  $SD = 13.9$ ) on the website. When new content was posted on the site, women spent between 4.5 ( $SD = 3.5$ ) and 18.3 ( $SD = 14.1$ ) minutes accessing new materials. On average, women spent up to 28 minutes ( $M = 12.6$  minutes,  $SD = 7.3$ ) reviewing material on the site during the four weeks they had access to the site. Women in Group 1 visited the site slightly more often ( $M = 3.3$  versus 2.6 visits) and spent more time ( $M = 13.6$  versus 11.4 minutes) on the

TABLE 1: Flow of the SALSA Study.

T1	Intervention	T2	Intervention	T3	No contact	T4
N = 50	Group 1: 4-week Latin dance Group 2: 4-week internet access	N = 43	Group 1: 4-week internet access Group 2: 4-week Latin dance	N = 41	4 weeks	N = 36

TABLE 2: Body composition, physical activity, dietary habits, and psychosocial measures by group and time point.

	Group 1 (dance first)				Group 2 (website first)			
	T1 (n = 25) M (SD)	T2 (n = 21) M (SD)	T3 (n = 21) M (SD)	T4 (n = 18) M (SD)	T1 (n = 25) M (SD)	T2 (n = 22) M (SD)	T3 (n = 20) M (SD)	T4 (n = 18) M (SD)
Body mass index (kg/m <sup>2</sup> )	30.1 (5.7)	30.3 (5.6)	29.2 (5.2)	29.0 (5.5)	29.3 (5.0)	29.7 (5.2)	29.9 (5.5)	29.3 (5.0)
% body fat	38.7 (8.0)	38.2 (8.6)	37.0 (8.0)	37.6 (7.9)	38.4 (5.9)	38.4 (6.0)	38.5 (6.6)	38.5 (6.2)
Leisure-time physical activity (min per week)	12.0 (10.6)	18.7 (16.9)	23.3 (15.8)	34.8 (16.5)	9.5 (10.2)	17.0 (11.7)	23.7 (15.3)	33.2 (16.0)
Fruit and vegetables (servings per day)	5.1 (6.5)	3.3 (4.2)	3.2 (4.9)	1.3 (0.8)	3.2 (3.4)	3.3 (1.9)	2.5 (2.4)	2.6 (2.2)
Fat intake (% kcal from fat per day)	30.1 (2.5)	31.2 (4.1)	31.4 (3.5)	31.4 (3.5)	31.7 (3.4)	30.9 (2.6)	30.4 (2.5)	31.1 (4.1)

Note: Group 1: Dance first, website second; Group 2: Website first, dance second.

site than women in Group 2, but these differences in visits ( $F(1, 39) = 1.14, P = .293$ ) and duration ( $F(1, 39) = .87, P = .356$ ) by group were not statistically significant.

**3.3. Physical Activity Levels While Latin Dancing.** Objectively measured accelerometer data indicated women spent an average of 9 minutes ( $M = 8.5, SD = 6.4$ ) doing moderate or greater intensity physical activity while doing Latin dancing. There were no differences between groups, suggesting that Latin dance instruction and intensity were similar between groups. Heart rate monitors measured minutes spent above, in, and below target heart rate zone, defined as between 60 and 85% of maximum heart rate determined by age, and average heart rate. Women spent an average of 25.1 minutes ( $SD = 20.4$ ) in and 3.6 minutes ( $SD = 8.5$ ) above, their target heart rate zone with an average of 93.2 beats per min ( $SD = 45.7$ ) while doing Latin dancing.

**3.4. Changes in Physical Activity.** All participants reported a significant increase in weekly leisure-time physical activity from T1 to T4 ( $F(3, 102) = 27.64, P < .001$ ). This increase is roughly equitable to seven, 15-minute sessions (or 105 minutes total) of moderate or greater intensity physical activity, sufficient to expend 367.5–735 kilocalories per week [40]. The frequency of weekly leisure physical activity also changed from “never/rarely” to “sometimes” from T1 to T3 ( $F(2, 37) = 12.61, P < .001$ ). There were no significant differences in changes in physical activity over time by group.

**3.5. Changes in Dietary Habits.** Participants in Group 2 had more stable fruit and vegetable consumption ( $F(1, 34) = 1.38, P = .018$ ) over the course of the study, while Group 1 decreased consumption over the course of the study from over five servings to just over one serving. Group 2 decreased the percent of calories they consumed from fat compared to

Group 1 ( $F(1, 24) = 5.12, P = .030$ ). In general, those who received the SALSA website first had more favorable dietary habits outcomes.

**3.6. Changes in Body Composition.** BMI increased significantly in both groups between T1 and T2 ( $t(42) = -2.38, P = .022$ ). However, there was no statistically significant change in BMI over time by group ( $F(3, 93) = .30, P = .824$ ). Percent body fat differed significantly over time by group ( $F(1, 31) = 5.54, P = .025$ ). Post hoc tests show that women in Group 1 decreased their body fat percentage from 37.7 to 36.7% between T1 and T2, during the Latin dance intervention, but were unable to maintain the loss after participating in the website arm of the study. Women in Group 2 had a similar experience but only lost 0.2% body fat during the Latin dance intervention compared to the 1% loss for Group 1.

## 4. Discussion

The SALSA study used an innovative hybrid strategy, employing face-to-face and internet techniques to generate interest and register participants to pilot test an innovative intervention to promote physical activity and fruit and vegetable consumption in women of color. We found that women of color were both willing and able to participate in an internet-based intervention. Women visited the site roughly once per week to print out materials and would not remain logged in for extended periods of time. Time spent on the site ranged from one to fifty minutes, suggesting some participants may have logged in simply to check for new content, while others spent time accessing tools, recipes and other information and materials while logged in. These findings are consistent with previous studies, which have shown that web-based behavioral treatment interventions have higher log-ins than web-based education interventions

[41]. Although group differences in site visits and duration were not statistically significant, women who received the dance intervention first visited the site twice as often as women who received the salsa website first. Log in dates and times indicate that most women in both groups were aware of the update schedule and willingly checked the site at least once per week.

During Latin dance sessions, heart rate monitors showed that women did close to thirty minutes of moderate-intensity physical activity, although accelerometer data showed women, on average, did fewer than ten minutes of moderate-intensity physical activity, suggesting accelerometers may not be sensitive enough to measure physical activity during dancing in overweight and obese women. Previous studies have found heart rate to be a better measure of energy expenditure and physical activity intensity during dancing, and studies have reported increases in heart rate equivalent to aerobic interval training [11]. We saw no group effect for reported physical activity; women reported increased physical activity regardless of order of intervention activities and reported maintaining increases in physical activity at postintervention and follow-up, suggesting that the Latin dance intervention was effective for regular physical activity adoption and short-term maintenance, consistent with previous studies of dance [19, 42].

Women who had access to the SALSA website first reported modest increases in fruit and vegetable and decreases in fat consumption immediately following the website intervention, but failed to maintain those healthy changes after participating in the Latin dance intervention. However, the women in Group 2 fared much better than those in Group 1. Perhaps focusing on dietary habits first may make for more successful dietary outcomes, compared to focusing on physical activity first. This is an area for future research; to our knowledge few studies (if any) have investigated the order of intervention effects on maintenance of health behaviors. Data suggest that the SALSA website was useful for initiating healthful behavior change but not maintaining it. Previous studies have had similar findings [43–45], suggesting that interactive features and prolonged access may promote sustained changes in dietary habits [43].

In addition to the original aims of the study, the SALSA study showed promise in the domain of preventing weight gain and potentially even modest weight loss. Interventions that focus on sustainable health behaviors and modest weight loss improve systolic and diastolic blood pressure, heart rate, total cholesterol and insulin resistance leading to improved cardiopulmonary function and decreased risk of CVD and diabetes [46, 47]. Even a 3.5 to 7% weight loss has significant clinical relevance and can improve health over the lifespan, and women who maintain weight loss experience added health and quality of life benefits [48]. Women reduced their percent body fat while doing Latin dancing. Although decreases were small, this suggests that women who participate in a longer study may experience increased benefit and see greater results.

The SALSA pilot study combined a creative study design with innovative measures. By combining a randomized controlled and crossover study design, all participants received

the benefits of both intervention arms. The innovative study design was a unique method to accommodate the community's desires for all to receive all study treatment benefits while maintaining scientific integrity. Although the crossover design satisfied community desires, the order of intervention activities may influence adoption and maintenance of healthful behaviors. Women who participated in the Latin dance group first increased their physical activity but did not improve their dietary habits, while women who participated in the website group first increased physical activity, improved dietary habits, and experienced greater changes in percent body fat. Further work is needed to determine whether order of activities is important for adoption and maintenance of healthful behaviors in a larger sample of women of color.

In addition to the unique study design, the SALSA study had several strengths. Internet-based recruitment, surveys and content on improving dietary habits were another innovative method to meet the community's needs and increase retention rates. Internet-based surveys and education materials allowed women to participate without the burden of commuting to the university each week, except for Latin dance sessions. Like interviewer administered surveys, internet-based surveys increase rates of data completion but allow more privacy and convenience, thus decreasing participant burden. However, survey-based assessments may be subject to self-reporting bias, reducing some confidence in the outcomes. The use of Latin dance as physical activity also responded to the community's requests for a fun, engaging and less "exercisey" type of physical activity and was easy to implement; however, caution is warranted as these findings are only specific to the population under investigation, and further research is done to generalize findings to other population groups.

The SALSA study was a pilot study to test the efficacy of a hybrid internet-based and Latin dance intervention. Future work is needed to test the long-term physical and emotional health benefits of participating in a Latin dance intervention. This project was fortunate to take advantage of the zeitgeist that has led to particular popularity of Latin dance. Although it is relatively easy to adopt new healthful habits, sustaining them over time is often difficult if the prevailing ecology does not support the new health habit. The Latin dances are not only popular and fun, they are also culturally tied to the fastest growing subgroup of the US population, suggesting that as the Latino population grows so will the transcultural popularity of Latin dances. Providing the fundamental skills to a diverse group of individuals that already fits within the prevailing social ecology cannot help but be sustainable.

The women who participated in this study, regardless of ethnicity, age, income or education, were able to learn how to dance, and increase energy expenditure related to physical activity and weight and appeared to have a wonderful time doing it. Latin dance is increasing in popularity among people from all walks of life and seems to serve as a physical activity that is unaffected by social standing. Anyone can learn Latin dance, and, in the world of dance, it is not how wealthy, smart, or attractive one is, but rather the knowledge

of the dance steps and joy on the dance floor that are most desirable. Thus, Latin dance may serve as an equalizing force, helping women to be more physically active with a strategy that is fun, easy, and widely available.

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## Research Article

# Population-Based Estimates of Physical Activity for Adults with Type 2 Diabetes: A Cautionary Tale of Potential Confounding by Weight Status

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At a population level, the method used to determine those meeting physical activity guidelines has important implications, as estimating “sufficient” physical activity might be confounded by weight status. The objective of this study was to test the difference between three methods in estimating the prevalence of “sufficient activity” among Canadian adults with type 2 diabetes in a large population sample ( $N = 1614$ ) while considering the role of weight status as a potential confounder. Our results revealed that estimates of physical activity levels vary by BMI categories, depending on the methods examined. Although physical activity levels were lower in the obese, their energy expenditure estimates were not different from those who were overweight or of a healthy weight. The implications of these findings are that biased estimates of physical activity at a population level may result in inappropriate classification of adults with type 2 diabetes as “sufficiently active” and that the inclusion of body weight in estimating physical activity prevalence should be approached with caution.

## 1. Introduction

At a population level, the method used to determine those meeting physical activity guidelines has important implications [1]. For example, estimating “sufficient” physical activity (PA) might be confounded by weight status. This is possible since an increase in mean weight status of a population may result in spurious estimates of increasing physical activity-related energy expenditure over time [2]. This hypothesis is particularly important for those who work with type 2 diabetes populations because weight loss is a salient clinical target and can be achieved through energy

restriction alone or in combination with an increase in energy expenditure. Consequently, as argued above, valid changes (i.e., increases or decreases) in PA patterns might not be entirely and therefore correctly captured. If this were to occur, assessing population-based strategies geared towards increasing physical activity and reducing body weight among adults with type 2 diabetes might be limited by measurement error.

Low physical activity levels in adults with type 2 diabetes have been widely reported [3–9] yet there appear to be some irregularities among these data. For example, being older [3, 6] and being female [7, 9] were reported to

TABLE 1: Methods of assessment.

Method	Calculation	“Sufficiently active” thresholds
Kcal	Hours per week of moderate intense activities $\times$ (4 METS) + hours of vigorous intense activities $\times$ (7.5 METS) $\times$ body weight (kg)	$\geq 800/\text{week}$
Met·mins	Minutes per week of moderate intense activities $\times$ (4 METS) + minutes of vigorous intense activities $\times$ (7.5 METS)	$\geq 600/\text{week}$
MVPA mins	Minutes per week of moderate intense activity + minutes per week of vigorous intense activity (unweighted for intensity)	$\geq 150$

be negatively associated with physical activity yet in other studies, age [7, 9] and sex [6] had no significant relationship with physical activity. We contend that this discordance reflects methodological differences in data synthesis and the thresholds used to quantify physical activity levels sufficient for health benefit, notably the use of weight dependent thresholds [9].

In response, we postulated that the methods for assessing self-reported physical activity might serve to explain some of the discordance. The objective of this study was to compare three different methods to classify individuals with type 2 diabetes as “sufficiently active” using a validated measure of physical activity instrument [10]. We hypothesized that the prevalence of those classified as “sufficiently” active (i.e., proportional estimates) would be different according to the method used to calculate weekly physical activity and that these differences would be confounded with the inclusion of body weight in indirectly estimating physical activity-related energy expenditure.

## 2. Method

**2.1. Subjects.** The current study is a component of the Alberta Longitudinal Exercise and Diabetes Research Advancement (ALEXANDRA) Study, a prospective assessment of physical activity determinants [8]. The participants in this study were residents in the province of Alberta, Canada ( $N = 1614$ ) with type 2 diabetes and were assessed at three time points: baseline, 6 months, and 18 months. Demographic characteristics, recruitment, and response rates have been previously described [8]. Briefly, participants were  $62.9 \pm 12.1$  years of age, moderately overweight to obese ( $\text{BMI} = 29.6 \pm 5.9 \text{ kg/m}^2$ ), and represented equally by sex (51.4% male), and 72.0% of the sample indicated were Canadian while 28.0% were either Arab, Asian, African, European, Aboriginal, or Latin/South American. The demographic characteristics of this study population generally reflect Canada’s and Alberta’s adult type 2 diabetes population in terms of age and sex distributions [8, 11]. Participants were recruited by (1) mailing questionnaires and consent forms to individuals from the Canadian Diabetes Association registry, requesting completion from those with diabetes or (2) through a random digit dialing method to recruit individuals living with diabetes in Alberta; households that were contacted could also nominate a family member or friend with diabetes. This study received ethical approval from the Health Research Ethics Board.

**2.2. Physical Activity Assessment.** Physical activity was assessed with the Godin Leisure-Time Exercise Questionnaire (GLTEQ) [10]. Participants were dichotomized as “sufficiently active” or “inactive” based on three different classifications as presented in Table 1: (1) the estimated *kilocalories method* (Kcal)(hours per week of moderately intense activities [ $\times 4$  METS] + hours per week of vigorously intense activities [ $\times 7.5$  METS]  $\times$  body weight (kg)); (2) the *Met.mins method* (minutes per week of moderately intense activities [ $\times 4$  METS] + minutes per week of vigorously intense activities [ $\times 7.5$  METS]); (3) the *unweighted moderate and vigorous method* (MVPA mins) (minutes per week of moderately intense activities + minutes per week of vigorously intense activities). Thresholds for categorization of “sufficiently active” for each method, respectively, were  $\geq 800/\text{week}$  for the kilocalories which is based on previous population surveys [2] and reflects achieving  $\geq 150$  mins of moderate activity/week for an 80 kg person [2];  $\geq 600/\text{week}$  for Met·mins (reflecting  $\geq 150$  mins of moderate activity/week); 150 minutes/week for MVPA mins. These thresholds were selected based on public health guidelines [12] and diabetes-specific [13, 14] guidelines for achieving moderate activity of at least 150 mins per week.

Related to the first two methods, in calculating the indirect estimate of weekly energy expenditure, the number of minutes was computed by multiplying the frequency and duration of (i) weekly minutes of moderate physical activity  $\times 4.0$  METS and (ii) weekly minutes of vigorous physical activity  $\times 7.5$  METS. The weekly minutes for moderate and vigorous were then summed for a total Met score. One minute of vigorous physical activity is equivalent to 1.875 minutes of moderate activity (7.5/4.0) based on the average Met levels for vigorous activity (Met level = 7.5) and moderate activity (Met level = 4.0) set by Brown and Bauman [2] and employed in the original paper of the ALEXANDRA study [8]. This weighting provides more credit for participating in vigorous activity. Individuals who accumulated  $\geq 600$  Met-minutes per week (Method Two) were classified as “adequately active for health benefit” while those who did not were classified as “inadequately active” [2]. This criterion reflects achieving 150 minutes of moderate activity [4.0 Mets] or 80 minutes of vigorous [7.5 Mets] activity per week, or any combination thereof [2].

**2.3. Statistical Analysis.** Using only baseline data, for each physical activity assessment method, one-way analysis of variance (ANOVA; with BMI as the independent variable)

TABLE 2: Means and one-way ANOVA results for each of the three methods of assessment.

BMI	N	Kcal			Met·mins			MVPA mins			
		Mean	SD	(n)	Mean	SD	(n)	Mean	SD	(n)	
<25	341	746.5	2051.4	(99)	853.6	1516.5	(135)	172.0	243.9	(115)	
25–<30	570	798.2	1675.6	(170)	767.7	1221.4	(208)	158.3	231.7	(181)	
≥30	704	650.4	1450.1	(175)	557.4	928.1	(182)	112.7	165.7	(156)	
$F = 1.3; P = .28$				$F = 9.0; P < .001$				$F = 12.2; P < .001$			

TABLE 3: Proportion of adults classified as “sufficiently” active based on the three methods stratified by BMI.

BMI	N	Sufficiently active based on Kcal n (%)	Sufficiently active based on Met·mins n (%)	Sufficiently active based on MVPA mins n (%)
<25	341	99 (29.0)	135 (39.6)	115 (33.7)
25–<30	570	170 (29.8)	208 (36.5)	181 (31.8)
≥30	704	175 (24.9)	182 (25.9)	156 (22.2)
		$\chi^2(2) = 4.4$	$\chi^2(2) = 26.1^*$	$\chi^2(2) = 21.4^*$

\*Significantly different ( $P < .001$ )

was used to examine whether physical activity (as a continuous variable) varied significantly across normal weight (BMI < 25.0), overweight (BMI 25.0–<30.0), or obese (BMI ≥ 30.0) categories. Chi-square tests were conducted to examine differences in the proportion of participants classified as “sufficiently” active across body weight status categories. The Kappa statistic was employed to examine agreement between the three methods, and effect sizes using Cohen’s  $h$  [15] were reported to assess the magnitude of differences between the methods.

Considering that the mean age of the study sample was ~63 years, a sensitivity analysis was also conducted with Met·mins set at the lower cutoff (i.e., weekly minutes of moderate physical activity ×3.0 METS and weekly minutes of vigorous physical activity ×6.0 METS to calculate total Met·mins). ANOVAs and chi-square analyses described above were repeated using this new Met·min variable.

### 3. Results

When examining physical activity levels for each method, ANOVA analyses revealed significant ( $P$ 's < .001) differences for Met·mins and MVPA mins but total physical activity did not vary across BMI categories using the estimated kilocalories method (see Table 2). Chi-square analyses also revealed significant ( $P$ 's < .001) differences in the proportion of those classified as sufficiently active for Met·mins and MVPA mins methods but not for the kilocalories method (see Table 3). Further, it is noteworthy that the obese group generally had similar proportions that were sufficiently active, regardless of the physical activity measure (see Table 3).

Estimates for those meeting “sufficient activity” guidelines for each method across BMI categories are shown in Tables 4(a), 4(b), and 4(c). In terms of relative comparisons, the Met·mins method was consistently higher for all weight categories. The largest proportion was found for the normal weight category in the Met·mins methods (39.6%) and

the smallest for the obese category in the MVPA mins method (22.2%). The magnitudes of the differences were the greatest when comparing the Met·mins and MVPA mins methods, with effect sizes ranging from .03 to .22. The discordance between the Kcal and the MVPA mins methods was moderately lower than that between the Met·mins and Kcal methods (effects sizes from .09 to .12) and the lowest for the Kcal and the MVPA mins methods (.05 to .10).

The sensitivity tests (ANOVA's and chi-square analyses) revealed significant differences for Met·mins ( $F = 8.6; P < .001; \chi^2 = 29.2$ ) but not for estimated Kcals ( $F = 1.2; P = .31; \chi^2 = 4.4; P = .11$ ). Kappa values across the three respective BMI categories (<25, 25–30, and ≥30) for the three methods were .90, .92, and .76 for the Kcal and Met·mins methods; 0.90, 0.89, and 0.85 for the MVPA mins and Met·mins methods; 0.81, 0.92, and 0.86 for the MVPA mins and Kcal methods.

### 4. Discussion

The objective of this study was to test the difference between three methods in estimating the prevalence of “sufficient activity” among Canadian adults with type 2 diabetes in a large sample, while considering the role of weight status as a potential confounder. In addition to the unique population, our study expands on the Brown and Bauman [2] methodology by including a third measure of physical activity (MVPA mins) in addition to kilocalories and Met·minutes scores in comparing physical activity prevalence.

Overall, our results for all methods are generally in agreement with previous prevalence estimates of physical activity which show that approximately 60–70% of adults with type 2 diabetes are not “sufficiently active” [3–7, 9]. However, our results suggest that estimates of physical activity levels vary by BMI categories, depending on the methods examined. Upon further comparison of methods considered appropriate for estimating physical activity, we suggest that

TABLE 4

(a) Comparison of agreement between Kcal method and Met·mins method across BMI categories.

Body mass index	Met·mins					
	<25		25–30		≥30	
	Inactive <i>n</i> (%)	Active <i>n</i> (%)	Inactive <i>n</i> (%)	Active <i>n</i> (%)	Inactive <i>n</i> (%)	Active <i>n</i> (%)
Kcal						
Inactive	206 (60.4)	36 (10.6)	361 (63.3)	39 (6.8)	506 (71.9)	23 (3.3)
Active	0 (0)	99 (29.0)	1 (0.1)	169 (29.7)	16 (2.2)	159 (22.6)
	Kappa = 0.77 ( <i>n</i> = 341) ES = 0.12		Kappa = 0.84 ( <i>n</i> = 570) ES = 0.10		Kappa = 0.85 ( <i>n</i> = 704) ES = 0.09	

(b) Comparison of agreement between Kcal method and MVPA mins method across BMI categories.

Body mass index	MVPA mins					
	<25		25–30		≥30	
	Inactive <i>n</i> (%)	Active <i>n</i> (%)	Inactive <i>n</i> (%)	Active <i>n</i> (%)	Inactive <i>n</i> (%)	Active <i>n</i> (%)
Kcal						
Inactive	220 (64.5)	22 (6.5)	385 (67.5)	15 (2.6)	521 (74.0)	8 (1.1)
Active	6 (1.8)	93 (27.3)	4 (0.7)	166 (29.1)	27 (3.8)	148 (21.0)
	Kappa = 0.81 ( <i>n</i> = 341) ES = 0.10		Kappa = 0.92 ( <i>n</i> = 570) ES = 0.05		Kappa = 0.86 ( <i>n</i> = 704) ES = 0.06	

(c) Comparison of agreement between MVPA mins method and Met·mins method across BMI categories.

Body mass index	Met·mins					
	<25		25–30		≥30	
	Inactive <i>n</i> (%)	Active <i>n</i> (%)	Inactive <i>n</i> (%)	Active <i>n</i> (%)	Inactive <i>n</i> (%)	Active <i>n</i> (%)
MVPA mins						
Inactive	206 (60.4)	20 (5.9)	362 (63.5)	27 (4.7)	522 (74.1)	26 (3.7)
Active	0 (0)	115 (33.7)	0 (0)	181 (31.8)	0 (0)	156 (22.2)
	Kappa = 0.87 ( <i>n</i> = 341) ES = 0.22		Kappa = 0.90 ( <i>n</i> = 570) ES = 0.15		Kappa = 0.90 ( <i>n</i> = 704) ES = 0.03	

the Met·mins method may be more appropriate even though it may categorize a larger proportion as sufficiently active relative to the other methods when stratifying by weight status.

When comparing the difference between the methods, we found the magnitude to be small (i.e., .03 to .22) according to Cohen's definition [15]: there were nonetheless differences worthy of comment. Most notably, the largest effect sizes were found between the MVPA mins and the Met·mins methods suggesting higher discordance between these methods. Overall, when classifying individuals as "sufficiently active" the magnitude of the differences between the methods appears to be consistent regardless of the stratification by weight status but the magnitude of difference appears to be lower for the Met·mins method. Although this difference may seem statistically trivial, the impact of such differences at a population level may be profound.

It is noteworthy (see Table 3) that although physical activity levels were lower in the obese, their energy expenditure estimates were similar with those who were overweight or of a healthy weight. This finding supports existing evidence indicating that the energy cost of physical

activity is greater in the obese [16]. Further, it is acknowledged that physical activity energy expenditure is important for weight maintenance and that weight maintenance is problematic because physical activity levels are low among this population. Consequently, because energy expenditure estimates at a population level are not always considered with physical activity surveillance, taking into account physical activity energy expenditure may be important in the obese population.

This study is not without caveats. First, our data were based on self-reported physical activity and may reflect a population who are more highly active and with lower body weights status. Second, the somewhat broad use of metabolic equivalents (MET) for estimating energy expenditure is imprecise as it should incorporate resting metabolic rate to more accurately gauge energy expenditure on an individual level. Third, since there is no established "gold standard" for self-reported physical activity, the addition of an objective measure (i.e., accelerometer) would have provided stronger support for our argument for the use of the Met·mins method when assessing physical activity in this population. Finally, future studies on this topic should examine physical activity change scores in longitudinal designs.

## 5. Conclusions

The implications of our study are that biased estimates of physical activity at a population level may result in inappropriate classification of adults with type 2 diabetes as “sufficiently active” and that the inclusion of a weight-dependent estimate (i.e., Kcal method) of physical activity prevalence should be approached with caution as 80% of individuals with type 2 diabetes are overweight or obese [17]. If a weight-dependent estimate of physical activity is used however, an estimate of weight stability should be included within the temporal reference with which physical activity behaviors are collected.

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