# Health & Fitness Journal

of Canada




Volume 12 September 30, 2019 Number 3

**ARTICLE**

## Can Regular Physical Activity Prevent Obesity? 3: Empirical Longitudinal Evidence and its Efficacy


**Roy J. Shephard[1]**

**1 Faculty of Kinesiology & Physical Education, University of Toronto, Toronto, ON, Canada**
***Corresponding Author: royjshep@shaw.ca***



**Abstract**

**Objective**. The objective of this narrative review is to examine longitudinal data pointing to the efficacy of adequate daily physical activity in the prevention of obesity. **Methods**. Information obtained from Ovid/Medline, Pub-Med and Google Scholar through to April 2019 has been supplemented by a search of the author's extensive personal files. **Results.** Babies that have a high level of spontaneous physical activity generally accumulate less body fat than their peers over the first few years of life**.** However, there is little evidence of a favourable response to supplementary exercise programmes in pre-school children, perhaps because of practical difficulties in augmenting habitual physical activity in this age group. Summer "obesity camps" for older children usually induce a substantial immediate decrease of both body mass and tissue fat stores, but it is unclear how far this reflects dietary restrictions at the camp rather than an increase of physical activity in this environment. Five of 8 uncontrolled longitudinal studies of children and adolescents with subjective assessments of habitual physical activity found no beneficial changes of body composition in individuals who were physically more active, as opposed to 3 positive reports (one of these seeing benefits in girls only). However, perhaps because more accurate categorization of exercise levels was possible, benefit was demonstrated in 8 of 10 trials of children with objective assessments of habitual physical activity. Fifteen of 26 trials of children and adolescents with group programme assignment also found a better body composition in those assigned to groups that were more physically active, although participants in 9 of these 15 trials were given not only an increase of physical activity, but also dietary advice and/or a restriction of food intake. Cohort studies in adults have found fairly consistently that regular physical activity reduces obesity or prevents the increase of body fat content usually associated with aging; benefit was seen in 14 of 17 studies of young adults, and 20 of 21 groups of middle-aged and older individuals. The portion of the day allocated to sedentary behaviour has also been associated with the development of obesity in 4 of 6 studies in children, and 10 of 13 trials in adults. Likewise, the transition from physically active hunting and gathering to an "urban" lifestyle has been associated with an accumulation of body fat in arctic Inuit. In children, randomized controlled trials have shown beneficial changes in body composition from interventions only when the intervention has been effective in achieving a substantial increase of daily physical activity. However 27 of 31 controlled studies of adults have demonstrated a reduction of body fat content in response to a variety of exercise initiatives. It is more difficult to assign a vigorous exercise programme to the frail elderly, and in this age group there has as yet been little study of the potential to reduce body fat by an increase in physical activity, although this would confer obvious functional benefit on those with limited muscle strength. **Conclusions**. Both in children and in adults, the bulk of prospective and controlled trials point to the efficacy of adequate volumes of regular exercise in both the prevention and the control of obesity. But as with initiatives based on rigorous dieting, the challenge to health professionals is to sustain the enthusiasm of clients over a sufficient period for a programme to take effect and to become a part of the individual's normal lifestyle. **Health & Fitness Journal of Canada 2019;12(3):3-92**.
https://doi.org/10.14288/hfjc.v12i3.278


*Keywords*: Acculturation; Infants; Kindergarten; Pre-school programmes. Fitness camps; Frail elderly; Randomized trials; Sedentary time

## Introduction

Nutritionists have sometimes argued against the efficacy of regular physical activity in the prevention and treatment of obesity, pointing to what they regard as the large energy expenditures needed to metabolize excess body fat, to the supposed immediate stimulation of appetite by a bout of exercise, and to the compensatory reduction of resting metabolic rate that is commonly induced by a negative energy balance. However, a detailed review of such fears has shown that they are overstated (Shephard, 2019a). Moreover, the literature contains consistent reports of substantial cross-sectional associations between regular engagement in vigorous physical activity and a low body fat content (Shephard, 2019b). Nevertheless, the interpretation of cross-sectional data is always difficult, and it could be argued that the observed associations reflect either a genetic predisposition of physically active individuals to a slim body build, or an association between an interest in exercise and the adoption of an overall healthy lifestyle, rather than a specific beneficial effect of exercise. Further, there might be some tendency to reverse causation, with an obese body build discouraging a person from participating in an adequate daily volume of physical activity.

More convincing proof of the efficacy of physical activity as a means of preventing obesity requires the mounting of longitudinal studies, preferably randomly controlled experiments, where large populations are distributed between a control group and a group who agree to participate conscientiously and effectively in a long-term exercise programme. There are now quite a few instances where such investigations have been attempted, both in children and in adults, but unfortunately it remains notoriously difficult to persuade the average person to persist with random assignment to vigorous exercise or a homeopathic control programme on the necessary long-term basis. One alternative is to look longitudinally at the changes in body composition induced by non-randomized trials of regular physical activity and sedentary behaviour. The present narrative review collects and evaluates not only randomized controlled trials, but also evidence garnered from these alternative sources of information.

Studies of infants, pre-schoolers, older children, adolescents, young adults, and middle-aged and older people have all examined possible associations between an increase of habitual physical activity and a prevention of the commonly-observed age-related increase in body fat content. Some investigators have found protection even from quite modest volumes of regular leisure activity, although benefits have at times been relatively small, and sometimes have had neither clinical nor statistical significance. Moreover, (perhaps in part because few workers are now employed in physically heavy jobs), benefits have been established less clearly for vigorous occupational and domestic activity than for participation in active leisure pursuits. In many instances, the chosen criterion of efficacy has been a decrease in body mass or body mass index (BMI), and in such instances the practical significance of any reported difference from the control group is increased, because active individuals have usually increased their lean mass at the same time that they have reduced their fat mass.

Information is also examined concerning the changes of body composition that have occurred in people who have progressively adopted a sedentary lifestyle. One particular example of this trend is found among indigenous populations, where increasing contact with modern society has brought about substantial and well-documented decreases in habitual physical activity, typically accompanied by an increase in body fat content. Finally, available randomized controlled trials are described for subjects of all ages.

### *Longitudinal studies of physical activity and body composition in in infants and pre-school children*

Spontaneous activity patterns in cohorts of infants and pre-school students have often been followed without any specific intervention, in order to determine how far the spontaneously chosen movement patterns of the child correlate with the subsequent development of obesity. In other instances, controlled studies have attempted (with varying success) to increase the physical activity pursued by subjects enrolled in the intervention arm of experimental nursery, pre-school and kindergarten classes. A recent review (Carson et al., 2017) found 57 reports (49 unique studies) that had examined associations between physical activity and various aspects of health in children within pre-school children. Three clustered randomized trials and one non-randomized intervention involving a total of 1100 participants found no differences of BMI between exercised and control groups. Likewise, in most of the less well-designed studies, the benefits associated with a high level of physical activity were negligible. Another review (Timmons et al., 2012) noted that in only one of 3 studies of infants during the first few months of life was the daily volume of physical activity related to the subsequent thickness of skin-folds.

Likewise, among pre-schoolers, only 1 of 4 randomized trials found that added physical activity offered some protection against the development of obesity, and then only in girls. In contrast, some protection against future obesity was seen in all of 3 cohort trials.

### *Studies of physical activity and obesity in infants*

Of seven studies examining the physical activity patterns of infants (Table 1), five found that a greater level of activity offered some protection against the accumulation of body fat over the next few years. However, in only one of these investigations had the observers made any attempt to increase the spontaneous activity of the infant.

Davies et al. (1991) recruited 33 infants at the age of 3 months. The total daily energy expenditure of each participant was assessed by the doubly-labeled water technique. Measurements of BMI and skin-fold thicknesses taken at 9 months and 2 years bore no relationship to the initial daily energy expenditures of these infants.
de Vries et al. (2015) studied children who were initially aged less than one year old. Nurses repeatedly visited and advised children in the intervention group, seeking to stimulate their habitual physical activity. After a follow-up of 2.5 yr, outcomes were compared with those in the control group. The intervention by the nurses apparently had no significant impact on either motor development or the habitual physical activity of the children, but at their final evaluation (perhaps because of dietary counseling?) the intervention group did show a small advantage in terms of the average

**Table 1: Longitudinal studies examining the relationship between the volume of physical activity of an infant and subsequent body fat accumulation.**

| Authors | Subjects | Programme | Findings | Comments |
|---|---|---|---|---|
| Davies et al. (1991) | 33 infants, initially 3 months old | Doubly-labeled water, BMI and skin-folds measured at 9 months & 2 yr | No relationship between physical activity at 3 months and skin-folds at 2 yr | |
| de Vries et al. (2015) | 161 children at well-baby clinics, initially aged <1 yr | Nurses advised intervention parents on stimulating physical activity over first year of child's life | At 2.5 yr, no gains of physical activity or motor development, but small advantage of skin-folds (7.4 vs. 8.1 mm) | Intervention girls also showed decrease in BMI and waist circumference 10% drop-outs from study |
| Ku et al. (1991) | 170 children followed from 6 months to 8.75 yr | Physical activity and skin-fold thickness measured from age 6 months | No relationship in girls. Boys activity at 3-4 yr influenced skin-folds at 8 yr | Parents collected 1-day physical activity records annually |
| Li et al. (1995) | 31 healthy children aged 6-12 months | Physical activity over 6 h of observation vs. body fat by DXT | Significant negative relationship of body fat to physical activity rating | At 12 months, p = 0.002 |
| Sijtsma et al. (2013) | Babies initially aged 9-months | Movement patterns at 9 months vs. wt. for height and waist circumference at 24 months | Extent of movement in infancy influences Z-scores of W/H and circumference at 24 months | |
| Stunkard et al. (1999) | 40 infants initiakky aged 3 months | Body fat (elec. conductivity) and skin-fold thicknesses at 12 months vs. energy expenditure (doubly-labeled water) | Body fatness unrelated to total energy expenditure at 12 months | Fatness influenced by food intake |
| Wells and Ritz (2001) | 26 infants initially aged 9-12 months | Physical activity diary and fatness at 2 yrs | Skin-folds (but not total fatness) related to activity at 12 months | Total body fat by $^{18}$oxygen dilution |

thickness of 4 skin-folds (7.4 vs. 8.1 mm). Among the girls, those visited regularly by the nurses also showed slightly lower BMIs and waist circumferences than control subjects. Some 10% of subjects dropped out of this programme over the course of the study.

Ku et al. (1981) followed children from an initial age of 6 months to an average of 8.75 yr; 170 of those who enrolled completed the trial. Parents made 1-day estimates of the child's physical activity annually throughout the follow-up period. Data for the girls showed no relationship between habitual physical activity and measures of obesity, but the boys those who were physically more active at ages 3 and 4 yr showed weak (-0.35 to -0.36) negative correlations between activity levels and body fat as content determined by hydrostatic weighing and skin-fold measurements.

Li et al. (1995) related dual x-ray absorptiometry estimates of body fat content in babies initially aged 6 months to their habitual physical activity, as estimated by 6 hours of careful observation of the child. At an age of 12

**Table 2: Longitudinal studies examining the relationship between habitual physical activity and body fat accumulation in pre-school children.**

| Authors | Subjects | Programme | Findings | Comments |
|---|---|---|---|---|
| Annesi et al. (2013) | ~ 500 children, initially aged 4-5 yr | 18 treatment classes (physical activity increased by 30 min/wk) vs. 8 control classes | Over 9 months, reduction of BMI, greatest in overweight children | Mainly African-American children |
| Bocca et al. (2014) | 75 children initially aged 3-5 yr | Multidisciplinary diet and physical activity programme | At 16 wks, and at 3 yr follow-up, intervention group had lower Z score for BMI and waist circumference relative to controls | |
| Bonvin et al. (2013) | Children initially aged 3.3 yr attending child-care centres | Attempts to increase physical activity in intervention group (n = 201) vs. controls (n = 187) | At 9 months, no significant gains in motor skills, physical activity, or BMI | Programme compliance variable |
| Butte et al. (2016) | 127 children initially aged 3-5 yr | 1-year correlates of body fat % and fat mass (kg) | Activity count not significantly related to body fat (% or kg) | Physical activity by accelerometer and doubly labeled water. |
| de Coen et al. (2013) | 568 children initially aged 3-6 yr | 2-year follow-up seeking correlates of obesity development | Risk factors for obesity included parental obesity, screen time > 1h/d & high soft drink intake | |
| Huynh et al. (2011) | 546 Vietnamese children initially aged 4-5 yr | 1-yr follow-up of factors correlating with obesity | Initial weight, neighbourhood safety & parental obesity influence BMI | No significant impact of questionnaire assessments of physical activity or diet on obesity |
| Klesges et al. (1995) | 146 children initially aged 3-5 yr | Initial questionnaire physical activity assessment, 2yr follow-up of BMI | BMI negatively correlated with baseline aerobic activity (r = - 0.32) | 40% of children overweight at baseline |
| Kromholz (2012) | 428 preschool children, initially aged ~ 4.5 yr | Intervention, added 20 min/day physical activity | 20-month intervention had no effect on BMI or skin-folds | Both groups had 45 min physical activity/week |
| Moore et al. (1995) | 97 children initially aged 3-5 yr | Twice annual 5-day activity assessments by accelerometer | Greater gains of skin-fold for inactive (boys -0.75 vs. +0.25; girls 1.0 vs 1.75 mm) by entry into Grade 1 | Part of Framingham children's study (5 skin-folds measured) |
| Mo-Suwan et al. (1998) | 292 kindergarten students, initially aged ~ 4.5 yr | 15 min walk and 20 min aerobics each day for 29.6 months | No change in BMI or skin-folds relative to controls | |
| Reilly et al. (2006) | 545 preschool children, initially aged ~4.2 yr | Three 30-min PA classes/wk for 24 wks, plus home exercise programme | No effects on BMI or physical activity relative to controls | Motor skills improved |

months, the two variables showed a significant negative inter-relationship,

with a probability of 0.002.

Sijtsma et al. (2013) looked at the opportunities for free movement in babies at the age of 9 months, and found that this was reflected in the Z-scores of weight-for-height ratios and waist circumferences.

Srunkard et al. (1999) studied 40 infants, initially aged 3 months. Body fat content was determined by an electrical conductivity method and by the measurement of 4 skin-folds. The body fat content at 12 months was unrelated to the total daily energy expenditure at 3 months, as determined by the metabolism of doubly-labeled water. However, fatness was correlated with food intake as determined by weighing the infants before and after feeding and by observations of suckling.

Wells and Ritz (2001) used a physical activity diary to assess exercise patterns in 29 infants initially aged 9-12 months. When they were re-examined at an age of 2 yr, superficial body fat (as assessed by skin-fold readings) was inversely related to the initial rating of physically activity levels, but total body fat (as determined by $^{18}$oxygen dilution) did not show such a relationship.

In summary, 5 of 7 studies of infants found a favourable association between early physical activity and subsequent body fat levels, although in one of the 5 reports, benefit was seen only in the boys. This finding possibly reflects innate inter-sex differences in the child's body metabolism.

## Studies of physical activity and obesity in pre-school children

The reported effects of modest physical activity interventions upon the subsequent body fat levels of pre-school children are summarized in Table 2. Most programmes have been organized in the context of kindergarten or pre-school classes, with the staff concerned having received varying levels of expertise in methods for the promotion of physical activity. Often, the intervention has attempted to change not only patterns of habitual physical activity, but also the child's diet.

Annesi et al. (2013) took a group of some 500 children initially aged 4-5 yr who were attending pre-school programme, dividing them between a treatment group who received 30 min/day of a behaviourally-based initiative intended to augment their habitual physical activity and a control group. About a third of the students were initially obese or overweight. At the end of 9 months, accelerometer data showed a slightly greater amount of physical activity in the intervention group than in the controls (30 min/week), but unfortunately, it was not possible to determine how much of the greater activity was programme-related, and how much of the additional physical activity had occurred of the child's own volition. Given the small increase in physical activity, it is not surprising that the final BMI values showed little effect of the intervention upon body composition in normal weight children. There was a detectable but small programme effect on BMI in those children who were initially obese (final values of 19.0 versus 19.5 kg/m$^2$), but this was not large enough to have great clinical significance.

Bocca et al. (2014) evaluated the effects of a multi-disciplinary diet and physical activity programme in 75 children who were initially aged 3-5 yr. After 16 weeks of treatment, and at a 3-year follow-up, the intervention group had the advantage over controls in terms of z scores for BMI and waist circumferences.

Bonvin et al. (2013) randomized children with an average initial age of 3.3 yr who were attending Swiss childcare centres between a control group and an intervention group where an attempt was made to use the normal staff of the centre to increase habitual physical activity. Unfortunately, the employees were not very successful in changing the behaviour of children in the intervention group. After 9 months, experimental subjects showed no advantage over the controls in terms of motor skills, and no significant increase in their habitual physical activity (at least as determined by accelerometer readings, collected on a single day). The BMI also remained similar for the 2 groups over the 9 months of observation. However, the experimental design was weak, since not all of the centres implemented all of the intended interventions. Predictors of a favourable outcome included the availability of highly motivated staff, free access of the child to movement space, and access to indoor equipment for physical activity.

Butte et al. (2016) studied 127 children initially aged 3-5 yr, Some cross-sectional associations were seen between their initial body fat content and their participation in moderately vigorous habitual physical activity as measured by both accelerometer data and the metabolism of doubly labeled water. However, when the children were followed for one year, the changes in body fat (whether expressed in kg or as a percentage) showed no correlation with the volume of daily physical activity that had been undertaken by the child over the year.

De Coen et al. (2013) followed 568 children initially aged 3-6 yr for 30 months, looking for correlates with the development of obesity over this period. Risk factors were found to include not only the child's initial body mass, but also obesity in either of the parents, a low level of maternal education, a daily screen watching time of more than an hour, and a high consumption of soft drinks. However, neither structured physical activity undertaken at the kindergarten nor the amount of physical activity undertaken at home were related to body composition outcomes.

Huynh et al. (2011) examined correlates of an increase in BMI over a one-year follow-up of 546 children initially aged 4-5 yr who were living in Ho Chi Min City, Vietnam. In a multivariate analysis, the initial body mass of the child, the safety of the neighbourhood, and parental obesity all influenced the likelihood of an increase of BMI over the year of observation, but no significant correlations were found between body composition and questionnaire assessments of habitual physical activity and diet.

Klesges et al. (1995) followed 146 children, initially aged 3-5 yr, for two years. Some 40% of this sample was initially overweight. Increases of BMI over the period of observation were associated with obesity in the parents. A high baseline aerobic activity, as assessed by a parental questionnaire and an increase of leisure-time physical activity were each weakly associated with a lower tendency to an increase of BMI over the 2-year follow-up (r = - 0.32 and -0.32 [ns] respectively).

Kromholz (2012) studied 428 pre-school children, initially aged ~4.5 yr. Both intervention and control groups received 45 min of physical activity per week at their pre-school, but the intervention group undertook an additional 20 min/day of exercise on each of the remaining 4 weekdays. Over a 20-month follow-up, the intervention improved motor performance, but the additional exercise was insufficient to affect either BMI or skin-fold thicknesses relative to the controls.

Moore et al. (1995) evaluated 97 children who were initially aged 3-5 yr as a part of the Tecumseh children's study. Habitual physical activity was measured twice annually, obtaining 5-day accelerometer records on each occasion; the average of these scores was used to make a binary classification of the children as "active" (above the median score), or "inactive" (below the median score). Small inter-group differences in the average change in 5 skin-fold thicknesses through to Grade 1 entry were found between the 2 categories of children (for the boys, -0.75 mm versus +0.25 mm, and for the girls +1.0 mm versus +1.75 mm). Further, the slopes of the increase in skin-fold thickness showed significant negative correlations with measures of the child's habitual physical activity.

Mo-Suwan et al. (1998) added a daily 15 minute walk and 20 min of aerobic exercise to the programme of the intervention group in a controlled study of Taiwanese kindergarten students initially aged ~ 4.5 yr. Over a 29.6 month follow-up, the intervention group showed no overall advantage over control subjects in terms of BMI or skin-fold thicknesses, although the girls in the intervention group did finally have a marginally smaller BMI than the controls (13.8 versus 14.5 $kg/m^2$).

Reilly et al. (2006) initiated a 22-week randomized controlled trial with 545 preschool children initially aged ~4.2 yr. The intervention group was given three 30-minute physical activity classes per week at their nursery school, and they also received home-based health education aimed at increasing habitual physical activity and reducing sedentary time. After 6 months, the intervention group had developed improved motor skills, but it did not differ from controls with respect to either habitual physical activity (as determined by accelerometry) or BMI.

In summary, longitudinal studies of pre-school children have as yet found little improvement of body composition as a result of deliberate attempts to increase habitual physical activity through interventions made in nursery school classes and kindergartens. In 7 of 11 studies, there was no effect. In one study showing benefit, the main emphasis of the programme was upon dieting, in one study benefit was seen only in those who were initially obese, and in the remaining two positive reports the observed effects were relatively weak. However, the problem seems as much the practical difficulty that kindergarten workers with limited skills have had in inducing any substantial increase over spontaneous movement in intervention groups as the absence of a positive effect of exercise upon body fat content in this age group.

### Longitudinal studies of physical activity and body composition in older children and adolescents

Longitudinal studies examining relationships between habitual physical activity and body composition in older children and adolescents have included evaluations of time spent at camps specializing in the treatment of obesity, school-based exercise initiatives with reports or objective assessments of habitual physical activity (Gittelson and Park, 2018), and reports about sedentary time, such as the number of hours spent watching television or other electronic devices. All long-term analyses have been complicated by issues related to inter-individual differences in growth patterns and in the speed of sexual maturation. Changes in body mass have generally been interpreted in terms of the individual's percentage or Z-score relative to the height/body mass norms of the U.S. Centers for Disease Control and Prevention.

**Effects upon body composition of attendance at "obesity camps"**

Obesity-treatment camps for children and adolescents have typically involved attendees in substantial (but poorly quantitated) volumes of daily physical activity, but the interpretation of data has been complicated by simultaneous and substantial changes of diet (not always clearly documented) and by a temporary reprieve from the adverse parental influences of a household where overeating and a sedentary lifestyle may have been the norm. Typically, such obesity camps have focused on the treatment rather than on the prevention of obesity, and although such an approach has often had immediate success, practical objections include the high unit cost of treatment and the need for repeated camp sessions over the course of childhood in order to maintain a healthy pattern of living. Problems usually arise from a rapid increase of food intake and a lack of persistence with exercise once the child returns to the family environment (Bar-Or et al., 1998).

Jana Parizková and her colleagues conducted some of the earliest studies on the efficacy of summer obesity camps in Czechoslovakia during the period of communist rule (Table 3). In 1965, 7 obese 11-12-year-old boys carrying an average of 17.2 kg of fat were subjected to a 7-week camp that involved daily physical exercise sessions and distance walking, plus a diet restricted to an energy intake of 7.1 MJ/day (Sprynarová and Parizková,1965). Hydrostatic data showed a 4.9 kg decrease of body fat over the 7 weeks of camp attendance, although unfortunately this was accompanied by small decreases in both lean tissue mass and absolute maximal oxygen intake (measured in L/min). No information was obtained on changes in body composition once the boys had returned home. In subsequent research, it was recognized as undesirable to impose severe restrictions on the food intake of developing children, since it could impede normal growth and development, and an attempt was thus made to achieve the desired beneficial changes in body composition by exercise programmes alone (Parizková, 1998).

Braet et al. (1997) compared various types of treatment in a sample of 205 obese children aged 11-12 yr who were at least 20% overweight, comparing data with findings for a second group of 54 obese children of similar age who served as waiting-list controls. One option, followed by 55 of the experimental group, was attendance at a summer camp (a 10-day event, with exercise sessions held 5 hours per day, a 6 MJ/day dietary allowance, and monthly follow-up sessions). Three similar groups of children received group therapy sessions, individual therapy sessions, or limited

**Table 3: Influence of summer camp attendance on body composition of older children and adolescents.**

| Author | Subjects | Programme | Findings | Comments |
|---|---|---|---|---|
| Braet et al. (1997) | 205 obese children aged 11-12 yr, >20% overweight | 10-day camp (5 h exercise/day, 6 MJ/d diet) vs. 3 other programmes + control group | Camp 14.7% weight loss, group counseling 13.1% weight loss | 19% drop-out rate. Benefits persisted >6 months after end of programme |
| Gately et al. (2000a, b) | 194 children aged ~12.6 yr | 8-week camp, fun-based skills learning, 5 x 90 min/d plus 2 weekly counseling sessions, food intake limit 5.6 MJ/d | Decrease of BMI in 80% of students; also decreases in skin-folds and waist circumferences | Benefits persisted at 1 yr (BMI 30.0 vs. 32.9 kg/m$^2$ in controls) |
| Karner-Rezek et al. 2013) | 28 children, obesity class I-III. aged ~ 13.8 yr (boys), ~15.1 yr (girls) | 8-week camp, 2 MJ/day energy deficit. Two 60-90 min aerobic exercise sessions/day | Fat mass decreased 23.8% in boys, 21.6% in girls, Wingate power increased 95.6% in boys, 100% in girls | Dual x-ray absorptiometry fat measures. No long-term data |
| Rauber et al. (2018) | 12 overweight or obese children aged 9-11 yr | 5-day camp, 3-month follow-up | 25% of children became active (1500-3000 MET-h/wk), 15% decrease in number of sedentary children. 2 mm decrease skin-folds, 2 cm decrease waist circumference | Weight loss maintained, further decrease of skin-fold during follow-up |
| Ruzic et al. (2007) | 20 diabetic children aged ~13 yr | 2-week camp, high vol. low intensity exercise | Diabetic control improved, only 2 hypo-glycaemic episodes over course of camp | Benefits disappeared 2 months after return home |
| Sprynarová and Parizková (1965) | 7 boys aged 11-12 yr | 7-week camp, exercises and walking, 7.1 MJ/day diet | Average 12.3 kg loss of body fat | Associated loss of lean tissue and max. aerobic power. No follow-up |

lifestyle advice. Dropouts from the 4 options were relatively similar, at ~19%. The weight loss was greatest for those assigned to the camp treatment (14.7%), although benefits were only a little smaller with group therapy (13.1% weight loss). The weight loss was seen within 3 months of beginning treatment, and it was maintained for at least 6 months after ceasing formal therapy.

Gately et al. (2000a, b) had 194 children with an average age of 12.6 yr attend an 8-week weight-loss camp with an emphasis upon the fun-based learning of physical skills; there were five of these 90-minute learning sessions per day, designed to develop both aerobic power and sports skills, and they were supplemented by 2 sessions of health, nutritional and behavioural instruction each week. Food intake was set at 5.8 MJ/day. Most of the group were from high socio-economic status families, Significant reductions in body mass were seen over the 8 weeks of camp attendance, although there were large inter-individual differences in response. One year later, the average BMI remained below its initial value in 89% of the students (average 30.0 vs. 32.9 kg/m$^2$ in controls); however, an initial 8-week decrease in body mass averaging 11.2 kg had decreased to a decrease of 1.3 kg by the end of the year (in part because of normal growth).

Karner-Rezek et al. (2013) studied 28 adolescents who were attending an 8-week summer obesity camp. Food intake was limited to create a 2 MJ/day energy deficit, and participants undertook two 60-90 minute sessions of aerobic exercise per day. The Wingate Test power output increased, by 96% in the boys, and by 100% in the girls, and dual x-ray absorptiometry data also showed a substantial decrease of fat mass over the 8 week programme, a drop of 23.8% in the boys and of 21.6% in the girls. Data were not obtained regarding the long-term efficacy of this programme.

Rauber et al. (2018) followed 12 overweight or obese children aged 9-11 yr who attended a 5-day educational and exercise camp with a 3-month follow-up programme. Over the course of this intervention, a quarter of the students who were involved became physically active, and sedentary behaviour decreased in 2 of the participants. The children who were studied in detail showed an average 2 mm decrease in skin-fold readings and a 2 cm decrease in waist circumferences over the 3 months. Moreover, the improved physical activity patterns and the beneficial skin-fold and waist circumference changes persisted and even increased over the follow-up period.

Ruzic et al. (2007) studied 20 diabetic children aged ~13 yr who attended a 2-week high-volume but low intensity exercise camp. This intervention induced favourable changes in the course of the diabetes, particularly a decrease in blood glucose and control of HbA1c levels, and there were only 2 hypo-glycaemic episodes over the course of the camp. However, beneficial changes were reversed within 2 months of returning home, because the students were no longer participating in either organized exercise sessions or well-controlled nutritional programmes.

Baranowski et al. (2003) attempted to enhance the long-term impact of a 4-week summer camp programme by adding a subsequent 8-week home internet intervention, but they found no significant benefit from this additional feature, in part because less than a half of the girls in the intervention group took the time to log onto the authors' web-site after they had returned home.

In summary, a number of authors have introduced camp programmes where vigorous exercise and health education have been combined with substantial dietary restriction. The immediate effects have generally included a substantial reduction in body fat content, and in some instances benefits have persisted for as long as a year following camp attendance. However, most investigations to date have been in the context of treating established obesity. Little attempt has been made to determine whether benefits were attributable to exercise or dietary restriction, and there remains a need to examine how far low-cost versions of such interventions could introduce a healthy lifestyle to children who are initially of normal weight, preventing them from becoming obese as they become older.

**Body composition and other types of exercise intervention in children and adolescents**

Many of the interventions proposed for children and adolescents have been undertaken in the context of treating rather than preventing obesity, and as with the summer camps, the primary goal has been to decrease body fat content, rather than to discern the importance of dietary counseling relative to an increase in physical activity as a means of achieving this objective. Further, the response to interventions has often been less than impressive, both in terms of the investigator's success in increasing habitual physical activity and in the resultant decrease in body fat stores (Zwiauer, 2000).

A cross-sectional study from four parts of Europe (Ekelund et al., 2004) found that only 1% of the variance in fatness of 9- to 10-year-old children was attributable to the time that they spent in vigorous physical activity. On the other hand, a review by Bar-Or and Baranowski (1994) reported several long-term exercise-based initiatives that had achieved a 1-3% decreases of body fat content in adolescents, with programmes of one year duration or longer being more effective than shorter-term interventions. Some of these studies also showed large increases in the participants' power outputs (W/kg) on the Wingate test following the programme. In the long term, activities incorporated into daily life (such as walking to and from school) were noted as being more effective than organized classes such as calisthenics or jogging.

Determinations of the increase in physical activity achieved by exercise interventions have in some instances been based on subjective measures (questionnaire or diary reports), sometimes on objective assessments (for instance, accelerometer counts or the metabolism of doubly-labeled water), and sometimes on arbitrary group assignment. In many reports, the interpretation of response has been complicated in that the promotion of greater physical activity promotion has been supplemented by dietary education and/or restriction of food intake.

***Studies with subjective ratings of habitual physical activity*.**

It is difficult to obtain reliable information on physical activity patterns from subjective methods such as questionnaires or diaries, even in adults, and this problem is even greater in children, in part because they engage in a wide variety of activities each of which are performed for only short periods, and in part because in younger children information about physical activity patterns must be obtained second hand, from the observations of parents and/or school teachers. Inevitably, this uncertainty weakens relationships between estimates of habitual physical activity and body composition (Table 4).

Berkey et al. (2000) examined one-year predictors of gains in BMI in a sample of 6149 girls and 4620 boys initially aged 9-14 yr. In the boys, such gains were related to the time spent watching television, and in the girls, a high food intake and a low level of habitual physical activity as reported on a youth questionnaire were also predictors. However, the impact of all factors predicting BMI was relatively small.

Bogaert et al. (2003) followed a small sample of 59 children initially aged 6-9 yr for one year. The change of the child's BMI Z-score over this period was unrelated to the amount of total, moderate or high intensity physical activity performed, as estimated by a 3-day diary, or to the time spent in TV viewing. However, the habitual physical activity of individual children was related to the

**Table 4: Longitudinal relationships between habitual physical activity, physical fitness, and increase of body mass, as seen in older children and adolescents where habitual physical activity was monitored subjectively.**

| Author | Sample | Follow-up | Findings | Covariates or Comments |
|---|---|---|---|---|
| Berkey et al. (2000) | 6149 girls, 4620 boys initially aged 9-14 yr | 1 yr | Gains of BMI in girls related to high food intake, TV watching and low physical activity. In boys, to high TV watching | All effects on BMI relatively small |
| Bogaert et al. (2008) | 59 children initially aged 6-9 yr | 1 yr | Change of BMI unrelated to physical activity or hrs of TV watching | Physical activity of child related to physical activity of parents |
| Brownell and Kaye (1982) | 63 obese children initially aged 5-12 yr | 10 wk | Behavioural modification, nutritional education and physical activity programme reduced body mass 4.4 kg | 3 of 14 untreated children also lost weight over 10 wks |
| Collipp (1975) | 25 children, initially aged 9-10 yr | 6 + 6 wk | Phase 1, physical activity alone-no effect.<br>Phase 2, physical activity + dieting, weight loss 5 kg | |
| Davison and Birch (2011) | 197 girls initially 5-8 yr-old | 2 yr | Increase of BMI related to parental interest in physical activity, but not to estimate of child's physical activity | Initial BMI, change in mother's BMI, father's energy intake |
| Kimm et al. (2001) | 2379 girls initially aged 9-10 yr | 10 yr | Physical activity not related to changes in skin-fold thicknesses | Age, diet, age at menarche |
| Mamalakis et al. (2000) | 466 M, 424 F children initially aged 6 yr | 6 yr | Parental reports of habitual physical activity Persistent physical activity did not predict body mass index, skin-folds or waist-hip ratio at 9 and 12 yr; | Sex, parents' health knowledge, endurance run time, region |
| O'Loughlin et al. (2000) | 2318 children initially aged 9-12 yr | 2 yr | Predictors of excessive wt gain in girls baseline BMI, low physical activity, no sports. In boys, baseline BMI only | Odds ratios for excess wt. gain in girls no sports 2.14, low physical activity 2.18 |
| Tammelin et al. (2004) | 2834 M, 2872 F, adolescents initially aged 14 yr | 17 yr | Remaining active vs. becoming inactive, odds ratio of being overweight (M) 1.49, obesity (M) 1.53, 1.51 (F), severe abdominal obesity (F) 1.80 | Education, occupational PA, alcohol, smoking, BMI at age 14 yr, maternal BMI and parity |

exercise habits of their parents.

Brownell and Kaye (1982) evaluated the effects of combined in-school behavioural modification and nutritional education plus an adaptation of the standard school physical activity programme (with an emphasis upon daily non-competitive games and aerobic exercise) in 63 obese children initially aged 5-12 yr. Initially, 34% of the group were overweight. Over 10 weeks of observation, body mass was reduced by an average of 4.4 kg, with 60 of 63 children replacing their previous steady increase in weight by a reduction of body mass. In contrast, only 3 of 14 untreated children showed a decrease of body mass over the same interval.

Collipp (1975) involved 25 children initially aged 9-10 yr in a two-phase programme. In the first phase of 6 weeks, they received only increased physical activity, and no change of body mass was seen. In the second phase, also of 6 weeks duration, physical activity was combined with dietary restriction, and their body mass then decreased by 5 kg.

Davison and Birch (2011) followed the BMI of 197 girls who were initially 5 yr old over a 2-year period. Increases in the BMI of these children were not significantly correlated with the mother's rating of the child's habitual physical activity relative to that of her peers, although there was a significant association between the increase of BMI and the parents' own interests in physical activity. Other significant correlates of gains in BMI included the child's initial BMI, the increase of BMI in the mother over the 2 yr of observation, and the father's energy intake.

Kimm et al. (2001) looked for possible differences in the development of obesity between "white" and black" girls. In both ethnic groups, the main determinant of body fat content was the individual's stage of sexual maturation. Three-day physical activity diaries were collected from 2379 girls who were initially aged 9-m10 yr. However, the extent of physical activity reported (MET-min/day) was not significantly related to changes in skin-fold thickness over the 10 yr of follow-up.

Mamalakis et al. (2000) obtained parental reports on the habitual physical activity of 6-year old children (466 boys and 424 girls). Again, this data was unrelated to body mass index, skin-fold thicknesses or waist-hip ratios as determined when the children reached the ages of 9 and 12 yr.

O'Loughlin et al. (2000) studied excessive weight gain in 2318 children initially aged 9-12 yr who were recruited from low-income, multi-ethnic neighbourhoods. In boys, the only predictor of excessive weight gain was baseline BMI, but in girls effects were also seen from the absence of involvement in sports outside of school, (odds ratio 2.14) and a low overall level of physical activity as seen in a 7-day recall physical activity questionnaire (odds ratio 2.18).

Tammelin et al. (2004) recruited a large sample of 14-year old students (2834 males, 2872 females). Over a 17-year follow-up, those who persisted with physical activity were compared with those who had become physically inactive. Among the latter group, the odds of becoming overweight and obese were, respectively, 1.49 and 1.53 for male and female students, and the odds of developing severe abdominal obesity were 1.51 and 1.80 relative to those who had maintained an active lifestyle.

In summary, 5 of 8 reports based on subjective determinations of habitual physical activity found no association of such data with subsequent weight gain, as opposed to 3 reports of such an association (one of these three being in girls only).

***Studies with objective ratings of physical activity***.

Objective ratings of habitual physical activity have substantially more accuracy than subjective assessments (Table 5). However, one common source of objective data (the use of pedometers and accelerometers) also fails to record substantial segments of childhood physical activity, including the effort involved in walking up hills, cycling to and from school and swimming. Nevertheless, a review of pedometer readings and measures of adiposity in children and adolescents (Miguel-Berges, Reilly, Moreno Aznar, and Jiménez-Pavón, 2018) noted that 30 of 36 studies showed significant negative relationships between the two variables.

Butte et al. (2007) studied accelerometer records for 897 normal and overweight Hispanic children and adolescents aged 4-19 yr. Physical activity levels declined in all students over the period of observation, but students who sustained >60 min per day of moderate or vigorous physical activity were not consistently less obese than their more sedentary peers, suggesting the importance of diet in the genesis of obesity.

Byrd-Williams et al. (2008) measured the treadmill maximal oxygen intake of 160 overweight Hispanic youth, initially aged an average of 11.2 yr. Over a follow-up of 4 yr, the initial aerobic power (presumably in part a surrogate of habitual physical activity) was inversely related to gains of fat mass in the boys, a 15% higher initial maximal oxygen intake equating to a 1.4 kg smaller increase in body fat content over the study. However, no such relationship was seen in the girls. Most girls had a poor initial aerobic fitness, and it was suggested that in this group food intake played a more role than habitual physical activity in determining gains in body fat content.

Byrd-Williams et al. (2010) examined 38 initially obese adolescents aged 15-16 yr; an exercise intervention failed to increase daily physical activity in the group as a whole, so attention was focused on those members of the group who themselves decided to increase their daily physical activity by 28% (~1 MJ/day), as verified by 7-day accelerometer readings. Over 16 weeks of observation, these individuals showed a 1.4 kg (0.8%) decrease in their body fat content, Danielson et al. (2018) followed 204 children initially aged ~p.8 yr for 2 yr. Gains of body fat as determined by dual x-ray absorptiometry were related to initial physical activity (4-day accelerometer recordings), aerobic fitness as determined by a cycle ergometer test carried to voluntary exhaustion, and initial levels of abdominal and total body fat.

Johnson et al. (2000) made tests on 95 children who were initially aged ~ 8 yr, retesting them annually for 3-5 yr. Increases of body fat as determined by dual x-ray absorptiometry over this period were strongly related to initial body fatness, and were also inversely related to aerobic power and gains of aerobic power (assessed by treadmill walking to exhaustion, and expressed in L/min), but increases of body fat content were unrelated to measures of habitual energy expenditure as assessed by the metabolism of doubly-labeled water.

**Table 5: Relationship between objectively monitored physical activity and obesity in older children.**

| Author | Subjects | Programme | Findings | Comments |
|---|---|---|---|---|
| Butte et al. (2007) | 897 U.S. Hispanic children and adolescents aged 4-19 yr | 3-5 day recordings of physical activity by accelerometer | % of subjects taking >60 min/day of mod. or vigorous physical activity not consistently related to risk of obesity | ? diet important in genesis of obesity |
| Byrd-Williams et al. (2010) | 38 initially obese adolescents | 28% increase of habitual physical activity verified by 7-d accelerometry | 1.4 kg loss of fat mass over 16 weeks | |
| Byrd-Williams et al. (2008) | 160 overweight Hispanic youth initially aged ~11.2 yr | Treadmill maximal oxygen uptake | Over 4 yr follow-up, 15% higher maximal oxygen uptake equates to 1.4 kg less gain of fat mass in boys | Gain of fat unrelated to initial aerobic power in girls |
| Danielson et al. (2018) | 204 children initially aged ~9.8 yr. | 2 yr | Phys activity, physical fitness and initial body fat all predicted gains of fat as measured by DXT | Accelerometry and cycle ergometer test |
| Johnson et al. (2000) | 95 children initially aged 4.6-11.0 yr | Annual assessments for 3-5 yr | Gains of body fat related to initial body fat and aerobic fitness, but not to physical activity as assessed by doubly-labeled water | Treadmill walk to exhaustion |
| Metcalf et al. (2008) | 307 children initially aged 5 yr | Four 7-day accelerometer records, subjects followed annually for 3 yr | BMI, 5 skin-folds, & waist circumference all unrelated to physical activity | |
| Moore et al. (2003) | 103 children, initially aged 4 yr | Physical activity monitored by Caltrac accelerometer for 8 yr | Upper physical activity tertile gained less BMI and skin-fold thicknesses | At age 11 yr, average skin-fold 14.8 mm vs. 19.0 mm |
| Raustorp et al. (2006) | 93 children initially aged 12-14 yr | Pedometer counts over 3 yr follow-up | Decrease of count associated with increase of BMI | Self-esteem important to maintenance of physical activity in girls |
| Riddoch et al. (2009) | 7159 children initially aged 12 | 2 yr | DXT body fat at age 14 less (-11.9% in boys, -9.8% in girls) if taking >15 min/day of moderate to vigorous physical activity | Accelerometry data |
| Treuth et al. (2003) | 88 normal weight girls initially aged 8-9 yr | Body composition followed for 2 yr | Parental obesity a strong predictor; negative relation of body fat to 24 h energy expenditure and peak oxygen intake | 24 h calorimetry and doubly-labeled water |

Metcalf et al. (2008) enrolled 307 children who were initially aged 5 yr in a programme intended to evaluate the appropriateness of governmental minimum physical activity guidelines from the viewpoint of metabolic health. Activity levels were assessed by annual 7-day accelerometer records until the children reached the age of 8 yr. Less than a half of the boys, and only one in eight of the girls met the current minimum weekly physical activity recommendations. Despite a small inverse association with overall metabolic health, the average of the 4 physical activity assessments showed no significant differences in several measures of increasing obesity (BMI, waist circumferences, and the sum of 5 skin-folds) between children with low and higher accelerometer counts, and likewise there were no significant correlations between markers of obesity and the minutes per day that individual children spent at an intensity of activity > 3 METs.

Moore et al. (2003) obtained objective data on the physical activity patterns of 103 children, using a Caltrac accelerometer. The monitor was typically worn for 3-5 d, twice per year. Over 8 yr of observation, beginning at an age of 4 yr, those in the upper tertile of physical activity (with 50% greater physical activity counts) had smaller gains of BMI and skin-fold thicknesses than the remaining students; their health advantage first appeared at the age of 6 yr, and developed progressively with time. By the age of 11 yr, the average of 5 skin-fold readings was 14.8 mm for the most active tertile, as compared with19.0 mm for the least active tertile. There were parallel differences of final BMI between the highest and lowest tertiles (18.6 vs. 20.3 $kg/m^2$).

Raustorp et al. (2006) followed 93 children initially aged 12 to 14 yr for 3 yr. Most students showed a substantial decrease of daily physical activity over this period, pedometer step counts decreasing by an average of 2547 steps/day, and this change was associated with a 1.9 $kg/m^2$ increase of BMI. In the girls, a good self-image was important to maintenance of a high daily step-count.

Riddoch et al. (2009) collected accelerometer data on 7159 children at the age of 12 yr. Two years later, those practicing at least 15 min of moderately vigorous physical activity per day had lower levels of body fat as measured by dual x-ray absorptiometry than those who did not meet this standard (-11.9% in boys, -9.8% in girls) .

Treuth et al. (2003) followed 88 normal weight girls initially aged 8-9 yr for 2 years, observing a strong influence of parental obesity on the accumulation of body fat over this period. The peak oxygen intake and the 24-hour energy expenditure as measured by doubly labeled water were both inversely related to the accumulation of body fat.

In summary, perhaps in part because levels of habitual physical activity were measured more accurately when using accelerometers or similar objective recording devices, habitual physical activity had a positive effect upon the subsequent accumulation of body in 8 of 10 investigations.

***Studies with group assignment of physical activity patterns***.

Most group-assignment studies in older children and adolescents have attempted to increase the habitual physical activity of participants by modifying traditional school physical education programmes

(Table 6). One review of school-based trials found 12 controlled investigations.

There was a greater impact upon obesity in the intervention than in the control group in 11 of these trials (Story, 1999). However, often the improvement in body composition reported for the children who were more active was relatively small.

Ara et al. (2006) compared 26 active and 16 inactive boys, initially aged ~9.4 yr. Over a 3-year period, the active boys practiced sports at least 3 times per week. Levels of body fat content were determined by dual energy x-ray absorptiometry. Both groups of students became fatter as puberty approached. However, the final values showed an advantage to the active boys in terms of both smaller percentage increases in the amount of body fat (+45.7% versus 66.1%) and in the absolute body fat content (9.4% vsersus11.0%).

Caballero et al. (2003) involved 1704 American Indian students from Grades 3-5 in a controlled 3-year trial. The study compared responses to the standard educational programme with an intervention where teachers sought to increase habitual physical activity (providing 3 additional 30-minute physical education classes per week), to improve diet and to involve the families of the children in general health maintenance. The intervention induced little change in the daily physical activity of the experimental subjects, as assessed by a motion sensor, and perhaps for this reason they showed no significant differences in their final BMI or skin-fold readings relative to findings in the control group. The daily energy intake of the experimental students was reported as reduced on a 24-hour dietary recall, but this was not confirmed by direct observation of the study participants.

Christiakis et al. (1996) followed 82 boys initially aged 13-14 yr for 18 months. The intervention group received nutritional guidance and participated in a physical fitness programme; they showed an average 3.5 kg decrease in body mass, but this was limited largely to those members of the group who initially were obese (>30% excess body mass).

Finkelstein et al. (2013) enrolled 285 students aged 6-12 yr in a clustered randomized controlled study. The intervention group was set an incentivized daily pedometer target reading, and additional physically active weekend events were arranged for them (although the latter were poorly attended). The intervention group increased their step count by ~1000 paces per day relative to the controls, but after 9 months, the average BMI of these students did not differ significantly from that of the controls. As in several of the studies discussed here, no more specific measures of fat accumulation were obtained.

Foster et al. (1985) evaluated a peer-led obesity prevention and treatment programme in 89 obese children from grades 2-5. Over 12 weeks, the provision of advice on diet and physical activity yielded a 0.15 kg decrease of body mass in the intervention group, as compared with a gain of 1.3 kg in control students. The intervention group also showed an improvement in self-concept.

Gorely et al. (2009) had 589 children aged 7-11 yr participate in a controlled trial of a multi-phasic attempt to increase their habitual physical activity. Teachers of the intervention group were given CD-rom instruction in health education, and an interactive web site was developed for the pupils. Highlight physical activity events were arranged, a local media campaign was held at intervention schools, and a summer physical activity planner was offered to the experimental students. At the end of 10 months, the level of physical activity in the intervention group had increased by a modest 9 min per day, as compared with a 10 minute/day decrease in the control students, and there were final inter-group differences in pedometer counts of 1500 steps/day. There were also lesser increases of a skin-fold prediction of body fat (0.9% versus 1.8% over the year), BMI (0.4 versus 0.9 kg/m$^2$) and waist circumference (0.8 cm versus 2.8 cm) in the intervention group relative to the controls.

Hollis et al. (2016) carried out a randomized controlled trial of physical activity on 1051 grade 7 students drawn from an economically disadvantaged area. At 12 and 24 months of follow-up, those involved in the physical activity arm of the trial demonstrated an advantage of body mass (-0.62 kg) and of BMI (-0.28 kg/m$^2$) relative to the control group.

Jetté et al. (1977) examined the effects of extracurricular sports activity on a small group of adolescent males aged ~15 yr. Biweekly lacrosse games of ~45 min duration were organized for 5 months, but participation in these games yielded no advantages of skin-fold thicknesses or body mass relative to control students. There were also no favourable changes in self-concept as a result of the sport participation.

Kain et al. (2004) assigned Chilean primary school children between an intervention (n = 2141) and a control group (n = 945). Those in the intervention group received dietary advice and 90 min of additional physical activity per week for 6 months. Those of both sexes in the intervention group showed improved aerobic fitness, as assessed by scores on a 20 metre shuttle-run. Body composition did not change in the girls; the boys showed a decrease of average waist circumference (-0.9 cm versus +0.9 cm), although there was no significant decrement in triceps skin-fold readings (-0.5 mm versus -0.9 mm) relative to the control group.

Lansky and Brownell (1982) compared the effects of behavioural modification with a programme that combined physical activity and nutritional education in 71 obese adolescents aged 12-15 yr. The subjects were initially on average 57% over their ideal body weight. Eighteen meetings were attended over three-and-a-half months; this led to an average 3.0% decrease in excess body mass with the behavioural approach, and of 2.1% with the exercise/nutritional intervention. The authors speculated that the better response to the behavioral approach may have reflected a more structured form of teaching. Lansky and Vance (1983) reported a further trial of a behavioural intervention. This focused on increasing physical activity and improving the eating habits of 55 overweight students aged ~13 yr. Forty-five minute sessions were held weekly for 12 weeks; at the end of this period, the excess weight of the intervention students had decreased by 5.7%, as compared with an increase of 2.4% in the control subjects. The authors noted that the involvement of parents was important to the success of their programme.

Mcmurray et al. (2002) studied a group of 1140 youth aged 11-14 yr. Students divided between four groups, enrolled at different schools. One group received 30 min of varied aerobic training, 3 times per week, a second group was assigned to a health education programme, and a third group received both of these treatments. At the end of 8 weeks, all four groups showed some increase in skin-fold readings, but increments were smaller in those receiving aerobic exercise (average 1.4 mm) or the combined treatment (0.9 mm) than in the educational group (1.9 mm) or the controls (3.7 mm). There were no inter-group differences in changes of BMI, but the 2 groups receiving the aerobic exercise also showed small increments of maximal oxygen intake as predicted from a sub-maximal cycle ergometer test. The authors did not comment on why the exercised students became fatter; this probably reflected in part pubertal changes, but in view of the short nature of the study, seasonal effects may also have been at play.

Neumark Sztainer et al. (2003) evaluated a multi-component physical education programme in 201 adolescent girls aged 15-16 yr. Students drawn from 6 schools were randomized between an intervention and a control group. The intervention was designed to make the larger girls feel comfortable when they were being physically active, and specially adapted exercise classes were held in place of the regular co-ed physical education programme. Observations were made initially, after 16 weeks of intervention, and 8 months later. The special physical activity classes were held 4 times per week, and they were supplemented by social support (offered on alternate weeks) and by nutritional guidance (also provided on alternate weeks). The intervention group showed a slight increase in their overall physical activity, and a small decrease of sedentarity both post-intervention and at the 8-month follow-up, but there was no inter-group difference of BMI at the end of the intervention.

Pangrazi et al. (2003) enrolled 606 Arizonan Grade 4 students in a trial where one third of the group were encouraged to engage in 30-60 min per day of self-monitored moderate and vigorously active play, one third supplemented this play by a variable amount of physical education, and the remaining students served as controls. The play and the combined options achieved similar pedometer counts (12,598 versus 12,763 steps/day, versus 11,180 steps/day in the control subjects, but neither initiative produced any improvement in the body mass index relative to controls over the 12-week trial.

Ruppenthal and Gibbs (1979) carried out a small-scale study on 14 intervention and 28 control students from Grade 1; all were initially obese. Over a 5-month programme that included 45 min per day of physical education and nutritional counselling, the average excess weight of the students decreased from 19.1% to 7.8% of height and age norms.

Sahota et al. (2004) undertook a randomized controlled trial of an obesity and lifestyle education programme on 634 British school children aged 7-11 yr. Over a 9-month period the intervention produced modest increases in vegetable consumption, but no changes of physical activity (as assessed by a questionnaire on the sport and physical activity students had undertaken over the previous week).

Sallis et al. (2003) involved 1109 middle-school students in a controlled study to assess an intervention that was intended to increase the amount of vigorous physical activity undertaken both in formal physical education classes and informally throughout the school day. Over a 2-year period, observers using special software noted that the physical activity of all students declined. There was a significantly smaller decrease of moderately vigorous physical activity per day in the boys (-15 vs. -18 units/day) but not in the girls from the intervention group; however, neither sex showed any decrease of body mass index relative to control students.

Schofield et al. (2005) studied a group of "low-active" adolescent girls, aged ~15.8 yr; these were assigned between three groups. One group followed a pedometer-based exercise prescription, a second were given a time-based exercise prescription, and the third served as controls. After 12 weeks, both of the intervention groups had increased their daily activity by an average of 2000-2500 steps/day, as determined by 4-day pedometer records. But (perhaps in part because of a relative short period of observation), there were no inter-group differences of BMI.

An early report by Seltzer and Mayer (1970) looked at the needs of obese public school children (48 boys in grades 4-6, and 141 girls in grades 4-9 year, with the sample being on average 40% overweight). The existing physical education programme was judged as unsuited to the needs of obese children, and specially--trained teachers instituted a programme that emphasized sustained vigorous aerobic activity, and encouraged the taking of additional exercise at the weekends. Responses of the experimental students were compared with data for a similar number of non-participants. Over 5 months, the programme was relatively successful in moderating body composition for the boys, with the increase in body mass limited to 1.34kg , as compared with 2.99 kg in the control students. However, in the girls programme benefits were much smaller. Girls from grades 4-6, showed a 2.50 kg increase in body mass, as compared to 2.90 kg in controls, with skin-folds increasing by 0.17 mm versus 0.20 mm, while corresponding numbers for those from grades 7-9 were 1.71 kg versus 2.64 kg and -0.08 mm versus +0.72 mm.

The Trois Rivières regional study (Shephard and Lavallée, 1993) was successful in completing a six-year quasi-experimental study of additional physical activity in 546 primary school students.
An agreement with the parents and local school boards allowed some classes at an urban and a semi-rural school to be assigned to an experimental programme where all students received an hour of specialist-taught physical education per day, while students in the immediately preceding and following classes continued with the standard programme of only a nominal 40 min of physical activity twice per week, led by the home-room teacher. The experimental students pursued a variety of physical activities in the aerobic training zone throughout their classes, and compliance with this requirement was monitored periodically by telemetric recording of the participants' heart rates. Further, diary records showed that the intervention group made no substantial compensatory reduction of their leisure-time physical activity relative to control students. The experimental group progressively developed greater aerobic power, muscular strength and physical performance than students in the control group, but they showed little advantage over the controls in terms of body fat content. The main reasons for this were that few students in either group were initially obese, and the experimental programme did not exert any control over the diet provided at home.

**Table 6: Relationship between physical activity and obesity as seen in longitudinal studies of older children and adolescents assigned to specific groups.**

| Authors | Subjects | Programme | Findings | Comments |
|---|---|---|---|---|
| Ara et al. (2006) | 26 active vs.16 inactive children, initially aged ~9.4 yr | >3 h/wk of sports activity, no dietary change | After 3 yr, final values of fat mass by DXT 9.4% vs. 11.0% | |
| Caballero et al. (2003) | 1704 American Indian children, grades 3-5 | Controls vs. programme to increase physical activity, improve diet & involve families in health | Reduced energy intake, reduced body fat, but little change of physical activity achieved | |
| Christiakis et al. (1996) | 82 boys initially aged 13-14 yr | 18 month trial | Net weight change of 3.5 kg in intervention group, limited to obese individuals (30% overweight) | Random assignment |
| Finkelstein et al. (2013) | 285 children aged 6-12 yr | Intervention group given pedometer target and extra weekend physical activity | No significant advantage of BMI in intervention group at 9 months | Clustered randomized trial |
| Foster et al. (1985) | 89 overweight children in grades 2-5 | 12-week peer-led advice on physical activity and nutrition | Weight loss 0.15 kg, vs. 1.3 kg gain in controls | Self-concept improved in intervention group |
| Gorely et al. (2009) | 589 children aged 7-11 yr | Multi-phasic intervention to promote physical activity | Intervention group showed less increase of BMI, waist circumference & % body fat at 10 months | Physical activity increased 9 min/d, vs. 10 min/d decrease, in controls |
| Hollis et al. (2016) | 1051 econ. disadvantaged grade 7 students | 12 month and 24 month (n = 985) physical activity promotion | Advantages of weight (-0.62 kg) and BMI (-0.28 kg/m$^2$) at 12 and 24 months relative to controls | Randomized controlled trial |
| Jetté et al. (1977) | 21 obese male students aged ~15 yr | Intervention group played 45 min lacrosse biweekly for 5 months | No difference in skin-folds or body mass changes between intervention and control groups | |
| Kain et al. (2004) | Primary school children, 2141 intervention, 945 control group | 6 month physical activity and nutritional intervention | Shuttle-run score increased in both sexes, boys improved BMI and waist circumference | Triceps skin-folds not significantly decreased in intervention group |
| Lansky and Brownell (1982) | 71 obese adolescents aged 12-15 yr, 57% over ideal weight | Behavioural modification vs. physical activity + nutritional education | 18 meetings over 3.5 months; excess weight decreased by 3.0% vs. 2.1% | Better results from more structured behavioural programme |
| Lansky and Vance (1983) | 55 overweight students aged ~ 13 yr | Behavioral sessions to modify physical activity and eating behaviour, 12 weekly 45 min meetings | Excess weight decreased 5.7%, vs. 2.1% increase in controls | Weight loss influenced by parental involvement |
| Mcmurray et al. (2002) | 1140 youth aged 11-14 yr | Aerobics (30 min, 3/wk), vs. education vs. education +aerobics vs. control | After 8 wks, increase of skin-folds in 4 groups 1.4 vs 1.9 vs. 0.9 vs.. 3.7 mm | No inter-group differences in BMI |
| Neumark Sztainer et al. {2003) | 201 girls, grades 9-12 | Multi-component physical ed. class vs. controls for 16 weeks, 8 month follow-up | No inter-group difference of BMI | Slight increase of physical activity, decrease of sedentarity post-intervention & at 8-month follow up |
| Pangrazi et al. (2003) | 606 Grade 4 students | Play vs. Physical ed. + Play vs. control | Pedometer counts 12,763 vs. 12,598 vs. 11,180 steps/d | No inter-group differences of BMI |
| Ruppenthal and Gibbs (1979) | Obese students in Grade one, 14 intervention, 28 controls | 45 min/day physical ed. plus nutritional advice. | Decrease from average 19.1% to 7.8% overweight over 5 months | No significant change of obesity in control students |
| Sahota et al. (2004) | 634 children aged 7-11 yr in Leeds, UK | Obesity-prevention programme | Modest increase of vegetable consumption. No change of physical activity | Questionnaire on sport and physical activity over previous week |

**Table 6 Continued**

| Authors | Subjects | Programme | Findings | Comments |
|---|---|---|---|---|
| Sallis et al. (2003) | 1109 middle-school students | Intervention intended to increase activity in physical ed. and throughout school day | Slightly smaller decrease of phy, activity over 2 yr in boys only, no change in body fat. | |
| Schofield et al. (2005) | 85 low-active girls aged ~15.8 yr | Pedometer vs. timed exercise prescription vs. control group | Over 12 wk, step count increased 2000-2500 steps/d with both interventions | No inter-group differences of BMI at 12 weeks |
| Seltzer and Mayer (1970) | 48 boys grades 4-6, 141 girls grades 4-9, initially ~40% overweight | Enhanced physical ed classes, nutritional education | Over >5 months skin-fold +0.02 vs +2.40 mm (boys), + 0.17 vs. +0.20, and -0.08 vs. +0.72mm (girls) | Need to re-orient phys ed. away from fit students |
| Shephard and Lavallée (1993) | 546 children grades 1-6 | 6 yr | Quasi-experimental allocation, 5 h/week of aerobic activity vs. control | No inter-group difference in body fat (but few obese students, no control of diet) |
| Sigmund et al. (2012) | 176 students, grades 1-3 | Pedometer or accelerometer monitored activity encouraged in intervention schools | Odds of obesity after 1 yr 3 times greater in control schools | Environment favoured physical activity at intervention schools |
| Sollerhed and Ejlertson (2008) | 132 children initially aged 6-9 yr | Physical ed. classes increased from 2/wk to 4/wk in intervention group | At 3 yr, BMI -0.32 vs. + 0.25 kg/m$^2$ Waist circumference -0.5 vs +0.4 cm | Physical performance also improved |
| Story et al. (2003) | 54 8-10-year-old Afro-American girls | After-school programme to increase physical activity, healthy eating | At 12 wks, no difference of BMI or DEXA body fat between intervention and controls | |
| Tanas et al. (T2007) | 190 overweight children | Medical counseling (n = 85) vs. 105 on dietetic programme | 73% of med. counseling group shows decrease of BMI, vs. 43% in dieters | |
| Warren et al. (2003) | 213 children initially aged 5-7 yr | 14 month programme, physical activity vs. nutrition vs. physical activity + nutrition vs. control | Increased fruit and vegetable intake but no changes of overweight or obesity | 17% drop-out rate |
| Zakus et al. (1981) | 22 girls aged ~14 yr old | 9 wk programme, eating and physical activity interventions | Decreased overweight in intervention group at 9 wks, further reductions at 8month follow-up. | Random assignment |

Sigmund et al. (2012) organized a 2-year non-randomized intervention with 176 children in grades 1-3 (students 6-9 yr). At 2 intervention schools, judged as environmentally favourable to physical activity in terms of the school and neighbouring environment, additional physical activity was promoted (physical education sessions, physical activity breaks during academic class-time, a longer recess, and post-school physical activities). Pedometer or accelerometer measurements demonstrated a substantially higher level of physical activity in the two intervention schools than in the 2 schools serving as controls (a difference of1718 to 3247 steps/day). Initially, children at the four schools on average had a similar body composition, but after one year, the odds of being overweight or obese was 3 times greater in the control than in the intervention schools, and this difference was even greater after 2 yr of follow-up.

Sollerhed and Ejlertson (2008) examined the impact of increased physical education instruction upon 132 primary school students initially aged 6-9 yr. In this study, no constraints were place upon diet, but physical education classes were increased from 2 to 4 times per week for the intervention group. At the end of 3 yr, students in the experimental group had an advantage on an 11-item physical performance test battery, and they also fared better in terms of BMI (-0.32 vs. +

0.25/kg/m$^2$) and waist circumference (-0.5 cm versus +0.4 cm).

Story et al. (2003) studied 54 Afro-American girls aged 8-10 yr. A half of the group followed an after-school programme that was intended to increase habitual physical activity and improve eating patterns. After 12 weeks, experimental students showed no significant differences of BMI or DEXA measures of body fat content relative to the control group.

Tanas et al. (2007) compared the efficacy of medical counseling versus traditional dieting in a sample of 190 overweight children. The medical counseling comprised 3 immediate consultations with a pediatrician on methods of increasing physical activity and avoiding sedentary habits, with reinforcing discussions at 6 and 12 months, 2 and 3 yr. After 3 yr, there was a decrease of BMI in 73% of the counseling group, compared with 43% in the dieters. Moreover, the respective percentages of students who had increased their BMI by >10% were 11.8% versus 25.7%, and the average BMI of those who were counseled decreased by some 10%, versus a gain of 2% in the dieters.

Warren et al. (2003) allocated 213 children aged 5-7 yr between 4 school- and family-based programmes (physical activity, nutritional counselling, physical activity plus nutritional counselling and control). The dropout rate was similar for all 4 options. at ~ 17%. The exercise component was intended to increase physical activity in daily life and to reduce the amount of television viewing. At the end of 14 months, fruit and vegetable intake had increased, but all 4 groups showed small and similar increases in their habitual physical activity. The final proportions of overweight and obese children remained comparable in all 4 groups.

An early pilot programme of Zakus et al. (1981) involved 22 girls aged ~14 yr in a random assignment to either a 9-week in-school intervention designed to increase physical activity and improve eating habits, or to a control group. At the end of 9 weeks, there were fewer obese girls in the intervention group than in the controls, and this advantage had increased at an 8-month follow-up.

In summary, of the 26 longitudinal studies with group assignment, 15 showed an advantage of body composition to those students where physical activity was encouraged. However, in 9 of the 15 trials with positive results, encouragement to greater exercise had been supplemented by nutritional advice.

**Longitudinal studies of habitual physical activity and obesity in adults**

Adult life is commonly marked by a progressive decline in habitual physical activity, with an attendant increase in body fat content. Numerous longitudinal studies have examined the efficacy of a deliberate increase in physical activity as a means of preventing and/or correcting this trend, both in young and in older adults. One systematic review and meta-analysis of studies lasting at least one year found a 5.0-8.5 kg weight loss over the first 6 months of increased physical activity, and benefits of 3-6 kg that were maintained for 48 months (Franz et al., 2007). However, interpretation of data is complicated, since in many of the published investigations, an increase of physical activity was supplemented by a substantial restriction of food intake. Fogelholm and Kukkonen-Harjula (2000) examined the intensity and volume of effective physical activity programmes, suggesting that the weekly energy expenditure needed to be increased by 6.3-8.4 MJ/week in order to induce significant beneficial changes in body composition, and they recognized that many of the published trials had failed to achieve or to maintain this level of added energy expenditure. Another meta-analysis, based on 39 studies and 617 subjects, compared high intensity interval training with cycle ergometry and running, finding that the interval training was the more effective method of reducing body fat stores (Maillard, Pereira, and Boisseau, 2018).

Other potential problems in the interpretation of relationships between habitual physical activity and changes in body fat content pointed out by Wareham et al. (2005) include difficulties in detecting changes in body fat content because of inappropriate methodology, associations between successful fat loss and exercise programme adherence, and associations between adherence to a regular physical activity programme and the adoption of a generally healthy lifestyle.

## Responses of body composition in young adults to an increase of physical activity

Numerous studies of young adults have made longitudinal examinations of the changes in body composition that occur in response to high levels of both occupational and leisure activity. Studies based upon occupational energy expenditure have had the advantage than any extra physical activity was usually pursued regularly, 5 d/wk and for several hours per day, although the intensity of effort was often poorly documented, and in many industries the physical demands decreased progressively with automation and the introduction of robotics. Also, when interpreting occupational comparisons, note must be taken of the important socio-economic and general lifestyle differences that usually distinguish workers in "heavy" and "light" occupations (Shephard, 2018c). A few of the leisure studies have made objective determinations of the weekly volume of exercise achieved by the supposedly "active" subjects.

## Occupational comparisons

Factors potentially confounding comparisons of fat accumulation between jobs with differing physical demands (Table 7) include not only the socio-economic issues already noted, but also job-entry discrimination based on body build, obesity-related differences in educational attainments, and (particularly in women), the influence of obesity upon marriage prospects (Glass, Haas, and Reither, 2010).

The percentage of 8726 Chinese women initially aged 18-23 yr who showed a change of obesity over a 4 year follow-up was significantly related to the extent of light and moderate intensity work-related activity that they had undertaken (Bell, Ge, and Popkin, 2002), and fat accumulation was also correlated with the time that the women had spent sitting at work each week.

Among a sample of 2488 men and women initially aged 20-45 yr, Bell et al. (2001) identified workers who had gained more than 5 kg of body mass over a 4-year period observation; these individuals were more likely to have a "light" rather than a "heavy" occupational classification (odds of 3.1 in men and 1.8 in women).

**Table 7: Comparisons off body composition in young adults based on vigorous occupational or leisure physical activity.**

| Authors | Subjects | Follow-up | Findings | Covariates and comments |
|---|---|---|---|---|
| **Occupational comparisons** | | | | |
| Ball et al. (2002) | 8726 F aged 18-23 yr | 4 yr | No association between weight gain and number of 20 min periods of moderate & vigorous activity per week, or time spent sitting per wk | Education, occupation, marital status, parity |
| Bell et al. (2001) | 2488 M & F 20-45 yr | 8 yr | Those gaining >5 kg body mass more likely to have light vs. heavy occupation (odds ratio 3.1 [M], 1.8 [F]) | Age, height, body mass, residence, income, education |
| Hou et al. (2019) | | Recent urbanization | 2.6 cm increase of abdominal circumference in urban group relative to rural residents | |
| Klesges et al. (1992) | 142 M, 152 F aged 25-52 yr. | 2 yr | Decline in work activity related to gain of body mass in women only | Smoking, alcohol |
| Monda et al. (2008) | 4708 M, 4697 F aged 18-55 yr | 9 yr | Occupational activity inversely associated with body mass in both sexes; in men, also inverse association with domestic activity | Age, height, urban residence education, income, energy intake |
| Monsivais et al. (2015) | 7201, 4539 adults | 43, 26 months | Increase of body fat with job loss; little relation to change in physical activity | Psychological factors probably important |
| Sarrafzadegan et al. (2014) | 6504 adults aged >35 yr | 7 yr | Little difference of gain in body mass between manual and sedentary workers | Age, smoking and education main determinants of change in body mass. |
| **Leisure activities** | | | | |
| Barefoot et al. (1998) | 3885 M, 841 F, mean age 19 yr | 21 yr | Exercise (hr/wk) negatively correlated with gain in body mass | Sex, BMI, smoking, depression |
| Christensen et al. (2012) | 98 overweight female health care workers | 1 yr | Intervention group had advice on diet, physical activity & behavioural training 1 h/wk. 6 kg decrease of body mass, BMI - 2.2 kg/m$^2$ No change of body mass in controls | |
| Després et al.(1984) | 12 men, 7 women aged ~23 yr | 20 wks | 4-5 times /wk 40-45 min cycle ergometry at 60-65% maximal oxygen uptake. Decrease of body fat (2.0% M, 2.6%F) and skin-folds (2.5, 0.6 mm) | Improvements of body composition lost with subsequent detraining |
| Fogelholm et al. (2000) | 442 M, aged 36-49 yr | 10 yr | Increase of leisure physical activity negatively associated with change in body mass. No effect on body mass from continued high or low level of physical activity or decrease of physical activity, | Age, weight at age 20 yr and at entry, smoking, health, alcohol, diet, occupation, marital status, former sports training |

**Table 7 Continued**

| Authors | Subjects | Follow-up | Findings | Covariates and comments |
|---|---|---|---|---|
| French et al. (1999) | 228 M, 882 F (mean age 35 yr) | 4 yr | Leisure physical activity reported in 1 or more of 4 yr not significantly related to changes in body mass | Age, diet, baseline values |
| Heitmann et al. (1997) | 2110 M, 2490 F twin pairs aged 18-39 yr | 6 yr | Physical activity at follow-up not associated with change in body mass over study | Age, zygosity, smoking, initial BMI, change of BMI in twin-pair |
| Lewis et al. (1997) | 1823 M, 2083 F aged 18-30 yr | 7 yr | Decrease of treadmill time to exhaustion related to gain of body mass in both sexes | Age, education, smoking, total energy intake, fat intake alcohol parity |
| Martin et al. (2015) | 179 adults, aged _ 37.8 yr | 2 yr | Switch to active travel or public transport to and from work decreased BMI 0.32 kg/m$^2$ | Switch to private transport increased BMI 0.34 kg/m$^2$ |
| May et al. (2012) | 325,537 adults aged 25-70 yr | 5 yr | Being physically active, never smoking and keeping to Mediterranean diet gained 0.54 and 0.20 kg less weight, waist circumference 0.95 and 0.99 cm less in men and women respectively. | Responses compared to subjects without healthy behaviours |
| Paeratakul et al. (1998) | 3484 working adults aged 20-45 yr | 2 yr | Increased physical activity reduced gain of body mass in women only ($p = 0.02$) | Diet smoking SES |
| Rainwater et al. (2000) | 539 M & F, mean age 37 yr | 5 yr | Interview, Stanford 7-day recall quiz. Change in physical activity not associated with change in body mass | Age, sex |
| Schmitz et al. (2000) | 2770 M & F aged 18-30 yr | 10 yr | 6 MET exercise > 2 h/wk for 11 months decreased body mass by 0.38 to 1.12 kg/yr | Age, education, alcohol, parity, smoking, fat intake |
| Sherwood et al. (2000) | 1044 health volunteers aged 20-45 yr | 3 yr | Physical activity, history, occ. & leisure activity all correlated with body mass gain over 3 yr. One high intensity ex. session/wk decreased wt 0.5 kg in men, 0.1 kg in women | Co-varied age, smoking, income, education & marital status |
| Zhang et al. (2017) | 45 obese young women | 15 wks. High-intensity interval or continuous training, 0.3 MJ/session, 3-4 d/wk, vs. control | Both treatments produced similar decrease of body fat (2.8 kg) | Interval training produced results with less time commitment |

There has been a rapid and planned transition of the Chinese population from the rigours of traditional rural life to sedentary employment in large modern cities over the last decade, and this has been accompanied by both a decline in overall habitual physical activity and an average 2.6 cm increase in waist circumferences (Huo, Mazroo, Banks, and Marshall, 2019).

Klesges et al. (1992) looked at the effect of changes in the physical demands of occupation, finding an apparent sex difference of response between 142 men and 152 women. Over a 2-year study, a decline in the physical demands of work was related to an increase in body mass of the women, but no such response was seen in the men.

Monda et al. (2008) also examined the benefits of occupational and domestic physical activity in terms of preventing weight gain in a Chinese population. They followed 4708 men and 4697 women over a 9-year period, finding that a high-level of occupational activity was significantly associated with a lower body mass in both sexes, In the men, a lower body mass was also associated with greater domestic physical activity.

Monsivais et al. (2015) examined the effects of unemployment in two samples of 7201 and 4539 British adults who were followed for 43 and 26 months, respectively. Gains of body mass occurred over this time, but they did not appear to be related to changes in daily physical activity. It was concluded that the psychological concomitants of job loss were largely responsible for the changes in body composition..

Sarrafzadegan et al. (2014) carried out a 7-year follow-up of 6504 Iranian adults aged >35 yr. They found little difference of weight gain between manual and sedentary workers over the course of their study. The main determinants of a change in body weight were age, smoking and the individual's level of education.

In summary, 5 of 7 occupational studies showed a lesser accumulation of body fat for people in "heavy" employment (although in 1 of the 5 studies, this effect was seen only in women). The 2 negative studies were for an investigation of Iranian workers, and for those losing their employment.

**Patterns of leisure activity**

As in the studies of children and adolescents, it is useful to distinguish self-reported physical activity from studies where objective measurements were obtained.

***Subjective measures of habitual physical activity***

Barefoot et al. (1998) related the reported volume of voluntary exercise (hr/wk) taken by a large sample of college students (3885 males and 841 females) to the gain in body mass observed over a period of 21 yr; an inverse association was found. A depressed mood state modified the tendency to weight gain, further decreasing body mass in those who were already lean and increasing mass in those who were tending to become obese.

Christensen et al. ( 2012) carried out a controlled trial to assess the impact of a work-place fitness intervention in a group of 98 obese female health-care workers. Over a one-year period, a half of the group was seen for one hour a week. They received advice on diet and physical activity as well as behavioural training. The programme led to a 6 kg decrease of body mass, with a 2.2 kg/m$^2$ decrease of BMI. However, control subjects showed no significant change in body mass over this same period.

Fogelholm et al. (2000) followed a group of 442 men initially aged 36-49 yr for 10 yr, noting whether their habitual physical activity had increased or decreased over this period. An increase of leisure activity was associated with a decrease of body mass (p =0.02), but weight change was not associated with maintaining either a high or a low level of physical activity, or with allowing physical activity to decrease.

French et al. (1999) adopted the rather weak physical activity criterion of self-reports of participation in leisure activity during at least 1 of the 4 preceding years. In a sample of 228 men and 882 women with an initial mean age of 35 yr, such reports were not significantly associated with 4-year changes in body mass. The authors concluded that programme organizers needed to emphasize consistency of lifestyle behaviour if beneficial changes in body mass were to occur.

Heitmann et al. (1997) followed 1571 monozygotic and 3029 dizygotic twins for 6 yr. Overall, changes in body mass were not associated with a simple 3-level categorization of the individual's leisure activity, but in the monozygous twins, the similarity of weight gain was greatest in the most active twin-pairs, suggesting that there was a 3-way interaction between genetic characteristics, habitual physical activity and weight gain.

Martin et al. (2015) looked at the impact upon BMI of a change in the mode of transportation to and from work in a sample of 179 adults initially aged ~37.8 yr. Over a 2-year period, a reported switch to active transport (walking or cycling) or the use of public transport with some walking was associated with a decrease in BMI of 0.32 kg/m$^2$. In contrast, those who switched from active to vehicular transport over the 2-year period showed a gain in BMI of 0.34 kg/m$^2$.

May et al. (2012) followed a large sample of Europeans (325,537 adults initially aged 25-70 yr) for two years. Over this period, those who were physically active, had never smoked, and adhered to a Mediterranean diet had a smaller weight gain (an advantage of 0.54 kg in men, 0.20 kg in women) and a lesser increase of waist circumference (an advantage of 0.95 cm in men, 0.99 cm in women) than those individuals who did not maintain a healthy lifestyle.

Mozafarrian et al. (2011) followed 120,877 U.S. women who were initially non-obese, for 4 yr. On average, their body mass increased by1.5 kg over this interval. Factors associated with weight gain included a variety of dietary items, but there was also an 0.8 kg difference of weight gain between the least active and the most active quintiles of the sample.

Paeratakul et al. (1998) found a substantial relationship between weight changes and fat intake (p = 0.0001) in a 2-year study of 3484 Chinese adults initially aged 20-45 yr. Over the two years, a greater level of physical activity was also associated with a decrease of BMI in the women (p = 0.02), but not in the men.

Rainwater et al. (2000) used a physical activity interview and the Stanford 7-day physical activity recall questionnaire in 539 Mexicans of mean age 37 yr. They found no associations between changes in habitual physical activity and changes in body mass.

Schmitz et al. (2000) examined data for 2770 male and female participants in the CARDIA study over a period of 10 yr. Subjects were initially aged 18-30 yr. Pariciation in two hours per week of exercise at an intensity of 6 MET was associated with a decrease in body mass of 0.38-1.12 kg/year, the loss of weight being 4-5 times greater in those who were already obese at baseline.

Sherwood et al. (2000) collected findings on 1044 health volunteers who were participating in a weight-loss promotion campaign. Body mass data for the next 3 yr were related to overall physical activity and to occupational and leisure activity. Those beginning at least one high intensity exercise session per week saw a decrease in body mass, averaging 0.5 kg in the men and 0.1 kg in the women.

**Objectively measured volumes of physical activity.**

Several studies obtained objective measures of physical activity for their subjects. Després et al. (1984) had 12 men and 7 women aged ~23 yr engage in measured amounts of cycle ergometry (40-45 minute sessions 4-5 times a week at intensities rising from 60% to 65% of their maximal oxygen intake) for a period of 20 weeks. This resulted in a decrease of hydrostatically determined body fat content (2.0% in the men, 2.6% in the women), with a decrease in the thickness of 7 skin-folds (averaging 2.5 mm in the men and 0.6 mm in the women). However, these favourable changes in body composition were lost quite rapidly over a subsequent period of detraining.

Ekelund et al. (2005) examined individually calibrated heart rate estimates of metabolism for 5.6 yr in a sample of 739 men and women who had an initial average age of 53.8 yr. They found a significant negative relationship between the average daily energy expenditure and the increase of body fat (as assessed by bio-impedance) in those subjects who were below the median age. On the other hand, no such relationship was seen in older individuals, where the body weight tended to remain stable.

Lewis et al. (1997) related the 7-year improvement of aerobic fitness as shown by an increase of endurance time on a graded aerobic treadmill test to the associated decrease of body mass in a sample of 1823 men and 2083 women initially aged 18-30 yr. They found an inverse relationship between gains of aerobic fitness and an increase of body mass in both sexes.

Tataranni et al. (2003) used doubly-labeled water to follow the metabolism of 92 non-diabetic Pima Indians who were initially aged 19-70 yr. Over 4 yr of observation, gains in body mass were inversely related to estimates of resting metabolic rate, but not to the average 24-hour average metabolic rate. However, an earlier study of the same population found that a high level of physical activity was protective against weight gain (r = -0.25 in males) (Zurlo, Ferraro, and Fontvielle, 1992).

Zhang et al. (2017) compared potential forms of exercise in a short-term (12-week) trial with 45 obese young women. Subjects were divided between a group that performed high intensity interval training 3-4 times per week, a second group that undertook continuous aerobic training demanding an equal total energy expenditure (0.3 MJ/session), and a control group. Both active treatments reduced body mass by 2.8 kg over the 12 weeks, although the time commitment per session was smaller for the interval-training group.

In summary, 14 of 17 longitudinal studies of young adults found that body fat decreased, or increased to a lesser extent in active individuals than in those who were more sedentary. Moreover, at least one of the 3 studies finding no relationship used only a weak measure of habitual physical activity.

**Responses of middle-aged and older adults** Many cohort studies of middle-aged and older adults have found associations between levels of habitual physical activity and longitudinal changes of body composition, although the interpretation of these observations is limited by many of the same issues already noted in studies of children and younger adults (Table 8).

Berk et al. (2006 ) followed 549 adults, 73% of whom were men, for a total of 16 yr, to a final age of 74 yr. An increase of habitual physical activity to 134 min/wk was not enough to reduce BMI relative to those members of the group who maintained a sedentary lifestyle. However, those subjects who attained an average of 261 min of exercise per week did achieve a lower final BMI. Moreover, it was noted that those with a low level of weekly exercise were more likely to die over the 16-year study (a risk averaging 1.3% versus 0.5% per annum).

Ching et al. (1996) reported on data for 22,076 male health professionals. Over a 2-year follow up, higher baseline levels of physical activity were associated with a reduced risk of becoming overweight (statistical significance of the trend, $p = 0.01$). The cumulative incidence of overweight decreased progressively from 5.3% in those with an energy expenditure of less than 6.9 MET-h/week to 4.2% in those with an energy expenditure >42.3 MET-h/week (a relative risk of 0.81). In contrast to the negative findings of Crawford et al. (1999), the risk of weight gain increased with the time spent watching TV ($p = 0.002$). Relative to those who watched TV only 0-1 h/week, the risk of obesity was 1.49 with >41 h/week of television viewing.

Coakley et al. (1998) examined data for 10,272 male participants in the health professionals follow-up study. In this sample, initially aged 40-75 yr, the min/wk of reported vigorous physical activity were negatively related to gains in body mass, after adjusting for a number of covariates. Over the 4 yr, an increase of exercise and a decrease of TV viewing were associated with an average body mass advantage of 1.4 kg.

Di Pietro et al. (1998) related physical fitness, as indicated by maximal tolerated treadmill speeds, to the weight gain as seen over 7.5 yr of observation. After introducing multiple co-variates, the weight gains seen in both sexes were smaller in individuals who had a higher initial level of aerobic fitness, and such individuals also had lower odds of developing a weight gain of 5 or 10 kg over the 7.5 yr. Di Pietro et al. (2004) also followed reported physical activity in relation to weight gain in a group of 2501 men aged 20-55 yr. Over a 5-year follow up, the weight gain for this group was accelerated in those decreasing their physical activity, and a 24-hour intensity of physical activity averaging more than 1.45 METs was needed for body mass to decrease.

Guo et al. (1999) completed an average 9.1-year follow-up on 102 men and 108 women with an initial age of 44 yr. In the men, those reporting a low or medium level of habitual physical activity gained 2.1 and 1.8 kg more weight than those with a high level of physical activity, with associated differences in body fat content. However, no such relationships were seen in women.

**Table 8: Effects of an increase in habitual physical activity upon the body composition of middle-aged and older adults.**

| Authors | Subjects | Follow-up | Findings | Comments |
|---|---|---|---|---|
| Berk et al. (2006) | 549 adults (73% men) followed to age 74 yr | 16 yr | Increase of exercise to 134 min/wk not enough to reduce BMI relative to continued sedentary living; lower BMI seen with 261 min/wk exercise | Low exercisers more likely to die over 16 yr (1.3% vs. 0.5%/yr) |
| Ching et al. (1996) | 22,076 M initially aged 40-75 yr | 2 yr | Higher baseline physical activity reduced risk of becoming overweight | Age, smoking, TV viewing |
| Coakley et al. (1998) | 10,272 M initially 40-75 yr | 4 yr | Vigorous physical activity (min/week) negatively correlated with gain in body mass | Age, diet, smoking, baseline physical. activity, and TV time |
| Guo et al. (1999) | 102 M, 108 F, mean initial age 44 yr | 9.1 yr | Low and medium physical activity show wt gain 2.1, 1.8 kg relative to high physical activity in men, but no advantage in women | Age, menopause, oestrogen use |
| Haapanen et al. (1997) | 2564 M, 2695 F initially aged 19-63 yr | 10 yr | If no regular leisure activity at end of study, odds of > 5 kg weight gain 2.59 (M), 2.67 (F) | Age, health, smoking, SES status |
| Kahn et al. (1997) | 35,156 M, 44,080 F mean initial age 40 yr | 10 yr | Greater jogging, aerobics, tennis, gardening or walking associated with significant BMI loss (0.08 to 0.49 kg/m$^2$) | Age, education, region, BMI at 18 yr and at entry, diet, alcohol, smoking, marital status, oestrogen use, parity |
| Kawachi et al. (1996) | 1474 female nurses initially aged 40-75 yr | 2 yr | Those who quit smoking & increased physical activity by > 8 MET-h/wk gained less weight than those who just quit smoking | Age, height, baseline weight, energy intake, fat and alcohol intake, hypertension, high cholesterol |
| Koh-Banerjee et al. (2003) | 16,587 M aged 40-75 | 9 yr | Increase of vigorous physical activity 25 MET-h/wk reduced waist circumference by 0.38 cm, 0.5 h/wk resistance training mm reduced by 0.91 cm and >20 h/wk TV viewing increased by 0.59 cm | Age, BMI, waist circumference, alcohol, energy intake, physical activity change in smoking, change in BMI |

**Table 8 Continued**

| Authors | Subjects | Follow-up | Findings | Comments |
|---|---|---|---|---|
| Macdonald et al. (2003) | 898 F aged 45-54 yr | 6.3 yr | Self-reported physical activity explained 4.4% change in body mass | Age, weight, smoking, energy intake |
| Mozafarrian et al. (2011) | 120,877 non-obese U.S. women | 4 yr | Weight change significant related to change of physical activity (0.8 kg difference of gain across physical activity quintiles) | Many dietary variables also influence change |
| Owens et al. (1992) | 500 women age 42-50 yr. | 3 yr | Initial Paffenbarger leisure activity estimate and increase of physical activity inversely associated with weight gain (p = 0.003, 0.01) | Smoking, sex hormone use, menopausal status |
| Parker et al. (1997) | 176 M, 289 F, mean initial age 47 yr | 4 yr | Initial participation in aerobics showed no association with subsequent weight change | Age, smoking, BMI, PA level, total energy expenditure |
| Rissanen et al. (1991) | 6165 M, 6594 F initially aged 25-64 yr | 5.7 yr | Leisure physical activity inversely associated with gain of body mass over follow-up in both sexes | Age, BMI, education, marital status, parity, smoking, alcohol, coffee, health |
| Taylor et al. (1994) | 568M, 668F initially aged 20-60 yr | 7yr | Increase of BMI least for those who increased physical activity over study | Age, sex, smoking |
| Voorrrips et al. (1991) | 45 older women (mean age 71 yr) | 59 yr (retrospective analysis) | Activity at age 12, 25, 40, 55 yr and currently inversely related to BMI | |
| Wagner et al. (2001) | 8865 men initially aged 50-59 yr | 5 yr | Change of BMI inversely associated with energy spent getting to and from work | Age, marital status. SES, alcohol, smoking, activity at work |
| Wanner et al. (2016) | 2224 M. 2264 F aged 37-81 yr | 8 yr | Highest vs. lowest physical activity tertile had odds ratio of 0.60 for high body fat content | Smoking, alcohol, health status |
| Williamson et al. (1993) | 3515 M, 5810 F, NHANES I cohort, initially aged 25-74 yr | 10 yr | Measured weight increase >13 kg related to low reported recreational activity at follow-up (RR low vs. high 3.1 in men, 3.8 in women) | Age, BMI, race, education, smoking, alcohol, health, parity |

**Table 8 Continued**

| **Objectively measured physical activity** | | | | |
|---|---|---|---|---|
| **Authors** | **Subjects** | **Follow-up** | **Findings** | **Comments** |
| Di Pietro et al. (1998) | 4559 M, 724 F, average initial age 43 yr | 7.5 yr | Gains of treadmill speed related to attenuated weight gain and lower odds of 5 or 10 kg weight gain in both sexes | Multiple covariates |
| Di Pietro et al. (2004) | 2501 M initially aged 20-55 yr | 5 yr | Weight gain accelerated in those decreasing physical activity; shift from low to moderate PAL (<1.45 to >1.45) needed for weight loss over time. | Age, height, smoking, follow-up time, change of smoking |
| Ekelund et al. (2005) | 311M, 428 F initial age 53.8 yr | 5.6 yr | Individually calibrated heart rate monitor shows inverse correlation of HR with body fat in those below median age | Age, sex, body composition, smoking, fat intake, duration of follow-up |
| McTiernan et al. (2007) | 102 M, 100 F aged 40-75 yr | 1 yr | Activity >375 min/wk (M), 295 min/wk (F) lost body mass (1.8 kg M; 1.4 kg F, 0.1 kg controls); also reduced fat mass & waist circumference | Gains increased with daily step count and with Adjusted for initial age, BMI, maximal oxygen intake |
| Tataranni et al. (2003) | 64 M, 28 F non-diabetic Pima Indians initially aged 19-70 yr | 4 yr | Doubly-labeled water estimate of physical activity index not associated with weight change | Age, sex, body composition, duration of follow-up |

Haapanen et al. (1997) followed 2564 men and 2695 women who were initially aged 19-63 yr for 10 yr. Those who reported no weekly leisure physical activity had increased odds of developing clinically significant (> 5 kg) weight gain by the end of the 10 yr. After multivariate adjustment of the data, the odds of a 5 kg weight gain in the sedentary individuals were 2.59 for men and 2.67 for women. Similar adverse odds were seen for those who decreased their physical activity over the 10 yr, were inactive throughout the 10 yr or were sitting at work, but these odds were decreased by 9% if there was standing or walking at work, and by 24% with 1 hour/day of brisk walking.

Kahn et al. (1997) followed 35,156 men and 44,156 women with an initial average age of 40 yr for 10 yr. The authors of this report took note of significant involvement in specific activities, including jogging, aerobics, tennis, gardening and walking. After adjustment for covariates, participation in any of the specified activities was associated with a significantly lower final BMI than that seen in controls (an advantage of 0.08 to 0.49 kg/m$^2$, the advantage being greater if the activity was pursued for >4/hours per week than if it was pursued for only 1-3 hours/week). The odds ratio for an increase in waist circumference was also reduced by participation in any of these activities, with particularly striking benefits being seen for those involved in jogging/running and aerobics/calisthenics (respective odds ratios of 0.57 and 0.59 with >4 hours/week of involvement in either of these pursuits).

Kawachi et al. (1996) conducted a 2-year study on 1474 female nurses initially aged 40-75 yr who were engaged in a smoking cessation programme. After adjustment for a number of co-variates, those who both quite smoking and increased their physical activity by >8 Met-h per week gained less weight than those who just quit smoking.

Koh-Banerjee et al. (2003) examined changes among 16,587 men aged 40-75 yr who had enrolled in a longitudinal study of health professionals. Over a 9-year follow up, an increase in vigorous physical activity of 25 MET-h/week (about 4 hours per week) and the initiation of 0.5 hours per week of weight training were associated with 3.8 mm and 9.1 mm decreases of waist circumference, respectively, while a 20 h/week increase of television viewing was associated with a 5.9 mm increase of waist circumference.

Macdonald et al. (2003) followed 898 women initially aged 45-54 yr for an average of 6.3 yr. The self-reported physical activity level explained 4.4% of the 3.3 kg change in body mass that was observed over the course of this study.

McTiernan et al. (2007) noted that men and women who engaged in substantial volumes of physical activity (375 min/wk in the men and 295 min/wk in the women) lost weight over a single year (1.8 kg in the men and 1.4 kg in the women, as compared with a negligible 0.1 kg change in controls. Active individuals also showed a lesser fat mass and a slimmer waist circumference. Moreover, the loss of body fat increased in parallel with objective measurements of the individual's daily step count and with gains in maximal oxygen intake, and in both sexes benefits were greater with >250 min/week of physical activity than with < 250 min/wk.

Mozafarrian et al. (2011) followed a sample of 120,877 non-obese U.S. women for 4 yr. The physical activity of participants was classified into quintiles, and the weight gain over the 4 yr showed an 0.8 kg difference between the top and bottom quintiles. Many dietary variables were also correlated with the extent of this weight gain.

Owens et al. (1992) followed 500 women, initially aged 42-50 yr for 3 yr. Leisure activity was measured with the Paffenbarger questionnaire, and after adjustment for co-variates both the initial level of physical activity and any change in physical activity over the 3 yr were inversely associated with weight gain ($p = 0.003$ and 0.01 respectively).

Parker et al. (1997) classified 176 men and 289 women of average initial age 47 yr according to their participation in aerobics programmes, over a 4-year follow-up, changes in body mass were unrelated to such participation after controlling data for their overall physical activity.

Rissanen et al. (1991) followed 6165 male and 6594 female Finnish adults for an average of 5.7 yr, making a 3-level questionnaire classification of their habitual leisure physical activity. After inclusion of a substantial number of covariates, the risk of substantial weight gain (>5 kg over 5 yr) was greater for those undertaking less physical activity, and both univariate and multivariate cross-sectional analyses of this data set showed an inverse relationship between physical activity and obesity.

Taylor et al. (1994) followed the BMI of 568 men and 668 women initially aged 20-60 yr for 7 yr. There was a general tendency for BMI to increase over this period, but the slope was less in those who decided to engage in more moderate and heavy physical activity than in those whose physical activity remained the same or declined (if expressed in $kg/m^2$ per year, the differences of BMI among non-smokers was in the men 0.08 vs. 0.13, and in the women 0.11 vs. 0.17, while the corresponding figures for smokers were 0.10 vs. 0.13 and 0.12 vs. 0.26).

Voorrips et al. (1991) made retrospective enquiry concerning the physical activity patterns adopted by 45 women aged 71 yr over the previous 59 yr of their lives The physical activity levels reported at the ages of 12, 25, 40, 55 yr and currently were all inversely related to the individual's body mass index.

Wagner et al. (2001) followed 8865 men who were initially aged 50-59 yr for 5 yr. After adjustment for several co-variates, the changes of BMI observed over this period were inversely associated with the energy subjects spent in traveling to and from work.

Wanner et al. (2016) carried out an 8-year follow-up on 2224 men and 2264 women initially aged 37-81 yr. The risk of developing obesity in their sample was associated with remaining or becoming inactive during leisure time over the 8-year interval. The highest physical activity tertile had an odds ratio of 0.60 relative to the lowest tertile in terms of developing a high body fat content as assessed by bio-impedance. Moreover, the odds of having more than 32% body fat relative to those who remained physically active was 1.18 for those who decided to become active, 1.35 for those who became inactive, and 1.60 for those who remained inactive. A similar degree of benefit was seen in terms of BMI, waist circumferences and weight-to-height ratios. However, no attenuation of fat accumulation was seen with involvement in occupational or domestic physical activity.

Williamson et al. (1993) completed a 10-year follow-up of data for 3515 men and 5810 women, initially aged 25-74 yr, who had participated in the NHANES I cohort A measured weight gain >13 kg was related to a low reported recreational activity at follow-up (the relative risk for those with low versus high habitual activity was 3.1 in men and 3.8 in women). Moreover, cross-sectional analyses showed a relationship of body mass to reported physical activity, both at baseline and at follow-up.

The 16-year longitudinal study of Beck et al. (2006) provides some clue as to the minimum volume of physical activity needed to avoid an accumulation of body fat. Those subjects who increased their weekly activity from less than 60 min to an average of 134 min did not show any significant attenuation of the in gain in BMI relative to those who remained inactive (+0.4 versus +0.9 $kg/m^2$), but those who maintained their level of physical activity throughout the study fared significantly better than those who decreased their physical activity (respective increases in BMI of 1.1 vs. 1.6 $kg/min^2$). McTiernan et al. (2007)

provided further evidence on dosage, noting that men and women who engaged in a substantial volume of physical activity (375 min/wk in the men and 295 min/wk in the women) lost weight over a single year (1.8 kg in the men and 1.4 kg in the women, as compared with a negligible change of 0.1 kg controls). The active individuals also showed a reduced fat mass and a slimmer waist circumference. Moreover, the loss of body fat increased in parallel with the individual's daily step count and with gains in maximal oxygen intake, and in both sexes, benefits were greater with >250 min/week of physical activity than with <250 min/wk. These 2 studies support the view that the threshold dose of physical activity for maintenance of a stable body mass is around 250 min of moderate physical activity per week.

Most of the studies listed above have looked at the benefits of leisure activity, but Wagner et al. (2001) looked at the effects of active commuting. Over a 5-year follow up, changes of body mass index in 8865 men aged 50-59 yr were inversely related to the energy expended in commuting. A weekly commuter energy expenditure of more than 10 MET-h was associated with a 1 cm smaller waist circumference and an 0.3 $kg/m^2$ advantage of BMI.

Benefits have also been linked to gains of aerobic fitness. Thus, Di Pietro et al. (1998) established that each 1 minute of increase in treadmill endurance time attenuated the age-related weight gain over a 7.5-year follow-up ($p = 0.001$); this amount of increase in aerobic performance was sufficient to reduce the odds of developing a 5 kg weight gain by 14% in men and by 9% in women, while the same gain of aerobic power reduced the odds of a 10 kg gain by 21% in both sexes.

Sometimes, the commonly observed age-related gain in body fat has been compounded by participation in a smoking cessation programme. However, Kawachi et al. (1996) noted that the 26% of former smokers who also increased their physical activity by an average of at least 8 MET-h/week gained less weight (1.8 kg) than those who simply quit smoking (2.3 kg). Moreover, this benefit was approximately doubled in those who increased their habitual physical activity by more than 16 MET-h/week.

In summary, in middle-aged and older adults, a physically active lifestyle generally reduced or prevented the usual age-related weight gain experienced by sedentary individuals. Active individuals had an unqualified advantage of body composition in 19 of 21 studies, in one the benefit was seen in men but not in women, and in one study added aerobics did not augment the benefits already gained from overall habitual physical activity. Although physical activity probably made a major causal contribution to these observed benefits, there may also have been effects from a greater overall health consciousness among individuals who chose to remain active relative to sedentary individuals, and the contribution of this influence remains to be clearly evaluated.

### Negative effects of excessive sedentary behaviour upon body composition

Further information on the relationship between regular physical activity and the accumulation of body fat can be obtained from longitudinal studies where people have adopted or maintained an excessively sedentary lifestyle behaviour, usually as evidenced by the time spent each week in watching television programmes and operating other electronic devices (Table 9).

The co-variation of data for sedentary behaviour often increases the inverse correlation between regular moderate physical activity and body fat content. However, there remains a need to clarify the direction of associations between body composition and a sedentary lifestyle. It may be that a substantial body fat content predisposes to sedentary living rather than the converse. Moreover, sedentary behaviour may not be an independent marker of an adverse lifestyle. Measurement of the time that a person allocates to sedentary pursuits may simply be identifying an individual who takes little overall physical activity. Certainly, the association between a fondness for sedentary pursuits and body fat content is weakened if a person's data is co-varied for habitual physical activity. With these caveats in mind, we will now summarize some of the more interesting reports on this issue in children and in adults.

**Studies of sedentary habits in children**

Berkey et al. (2000) found that in boys aged 9-14 yr, gains of BMI were associated with the time that they spent watching television, but in girls of the same age, the increase of BMI was related not only to the time that they usually spent watching television, but also to a high food intake and a low level of habitual physical activity.

Dennison et al. (2004) attempted to reduce television viewing in a half of a sample of 43 pre-school children aged ~3.9 yr. Unfortunately, educational sessions for the parents had only a borderline effect on the sedentary behaviour of the infants, and not surprisingly there was no inter-group difference in body mass or skin-fold thicknesses between intervention and control groups 6 months later.

Francis et al. (2003) applied a path analysis technique to data for t173 girls who were examined at the ages of 5, 7 and 9 yr. Those girls who spent more time watching television had a greater increase of BMI over the 4-year interval, but the authors suggested that this was mediated mainly through increased snacking while watching the television rather than by the sedentary behaviour itself.

Hancox et al. (2004) followed 1037 3-year old children for 23 yr, finding that watching television for >2 hr or more per day between the ages of 5 and 15 yr accounted for 17% of their excess weight as seen at the age of 26 yr (p= 0.012).

Proctor et al. (2003) also looked at the effects of extensive TV watching in 106 children who were initially aged 3-5 yr. At the end of a 7-yr follow-up, those who watched the television for more than 3 hours/day had skin-folds totaling 106.2 mm, whereas those watching less than 1.75 hr of television per day had a total of only 76.5 mm.

A small pilot programme for Afro-American girls (61 students aged 8-10 yr) was intended to increase physical activity and reduce television viewing (Robinson et al., 2003). Free 2.5-hr dance classes were provided 5 d/wk for the intervention group. Findings for these girls were compared with those for students who received only monthly health lectures and a health newsletter. The authors concluded that their programme had no effects on physical activity, body mass or waist circumferences.

**Table 9: Reports of a longitudinal relationship between sedentary behaviour and fat accumulation.**

| Author | Sample | Intervention | Findings | Comments |
|---|---|---|---|---|
| **Studies in children** | | | | |
| Berkey et al. (2000) | 6149 girls, 4620 boys aged 9-14 yr | 1 yr | Gains of BMI in girls related to high food intake, TV watching and low physical activity Boys related to high TV watching only | All effects on BMI relatively small |
| Dennison et al. (2004) | 43 pre-school children aged 3.9 yr | Educational sessions for parents to reduce child's TV viewing | At 6 months, borderline reduction in TV viewing in intervention group. No effect on body mass or skin-folds | |
| Francis et al. (2003) | 173 girls assessed at 5, 7 and 9 yr of age | Girls watching more television had larger increase of BMI over 4 yrs | Probably mediated through increased snacking rather than sitting | Path model analysis |
| Hancox et al. (2004) | 1037 children initially aged 3 yr | 23 yr | Watching TV >2h/day accounts for 17% of overweight at age 26 yr | Sex, SES, BMI at age 5 yr, parental BMI |
| Proctor et al. (2003) | 106 children aged 3-5 yr | 7 yr | TV and video viewing >3h/d vs. <1.75 h/d; skin-folds 106.2 mm vs. 76.5 mm | BMI, physical activity, fat & total energy intake, education, parental BMI |
| Robinson et al. (2003) | 61 F ages 8-10 yr | Free 2.5 h dance classes 5 d/wk + attempts to reduce TV viewing vs. monthly health lectures & newsletter | No effect of intervention on physical activity, body mass or waist circumference over 12 wks | |
| **Studies in adults** | | | | |
| Ching et al. (1996) | 22,076 M initially aged 40-75 yr | 2 yr | >41 h/wk TV watching increases risk of obesity 4.06 fold | Benefit apparently independent of physical activity level |
| Coakley et al. (1998) | 19,478 men | TV use over 4-yr follow-up | Decrease of TV watching associated with modest weight loss | |
| Crawford et al. (1999) | 176 men, 705 women | TV viewing vs. BMI | Positive association seen in women but not in men | Association strongest in low income women |

**Table 9 Continued**

| Author | Sample | Intervention | Findings | Comments |
|---|---|---|---|---|
| Ekelund et al. (2008) | Middle-aged adults (176 M, 217 F) | Heart rate estimate of sedentary time over 5.6 yr follow-up. | Fat mass & waist circumference associated with sedentary time over 6 yr follow-up | Reverse causality in longitudinal predictions |
| Hu et al. (2003) | 50,277 women with initial BMI < 30 kg/m$^2$ | TV viewing | Over 6-yr follow-up 2 h/d increment in TV viewing increases obesity 23%, 2 h/d sitting at work gives 5% increment | Data adjusted for age, smoking, physical activity & diet |
| Johanssen et al. {2008) | 10 lean, 10 obese women | Time sitting and standing measured over 10 d. | Obese women sat 2.5 h longer and stood 2 h less per day | |
| Koh-Banerjee et al. (2003) | 16,587 M aged 40-75 | 9 yr | >20 h/wk TV viewing increased skin-folds by 3.0 mm | Age, BMI, alcohol, energy intake, physical activity, change in smoking habits, change in BMI |
| Myers et al. (2017) | 71 adults | Sense-arm band worn for 7 d & dietary questionnaire completed | Sedentary behaviour positively correlated with fat mass and waist circumference | |
| Mortensen et al. (2008) | 4596 middle-aged men and women | Sedentary lifsstyle investigated relative to BMI over 13 yr follow-up | BMI predicted becoming sedentary, but sedentary behaviour did not predict increase of BMI unless account taken of changes in physi. activity | |
| Qi et al. (2012) | 7749 women, 4564 men | TV watching | Genetic predisposition to obesity enhanced by TV watching | |
| Raynor et al. (2006) | 1422 registrants in US weight control registry | Reported TV viewing | 1 yr weight gain associated with baseline TV viewing & increases in TV viewing | Data controlled for diet and physical activity |
| Staiano et al. (2018) | 71 adults aged 20-35 yr | Sedentary time measured by accelerometer | High sedentary time predicted baseline but not future obesity | |
| Vioque et al. (2000) | 814 men. 958 women | Watching TV > 4h/d vs. < 1 h/d | Odds ratio of obesity 2.38 | |

**Studies of sedentary habits in adults**.

Ching et al. (1996) carried out a 2-year study on 22,076 men initially aged 40-75 yr. A higher baseline physical activity reduced the risk of becoming overweight, but prognosis was also influenced by the extent of television viewing. In those watching the television or using a VCR more than 41 hours/week, there was a 4.06-fold increase in the odds of becoming overweight, with this disadvantage apparently being independent of physical activity levels.

Coakley et al. (1998) found that in a study of 19,478 men, a decrease of television watching was one of several factors associated with a modest weight loss over a 4-year follow-up.

Crawford et al. (1999) made a cross-sectional comparison between the television viewing habits and BMI in 176 men and 705 women. A positive association was seen in the women but not in the men, this relationship being strongest for lower socio-economic status women.

Ekelund et al. (2008) noted that in a sample of middle-aged adults (176 men and 217 women aged ~ 50 yr), fat mass and waist circumference were both related to the amount of time spent viewing television.

Hu et al. (2003) completed a 6-year follow-up of 50,277 women participating in the Nurses' Health Study, focusing on those women whose initial BMI was less than 30 kg/m$^2$. After allowing for the effects of age, smoking, physical activity and diet, for each 2 hours per day of television watching, the relative risk of developing obesity over the 6 yr increased by 23%, and each 2 hours/day that was spent sitting over this period also increased the risk by 5%, Habitual physical activity and diet were also associated with age and sex-adjusted fat mass and waist circumference, both at baseline and at follow-up (when fat mass had increased by an average of ~ 2 kg). The data further suggested that fat mass predicted the likelihood of future sedentary behaviour.

Johanssen et al. (2008) examined the role of posture allocation in 10 lean and 10 obese women over a 10-day period. They found that the obese women sat for 2.5 hours longer each day, and were standing for 2 hours less than those who were lean.

Koh-Banerjee et al. (2003) studied 18,587 men initially aged 40-75 yr for 9 yr. Self-reports of watching television for more than 20 hours per week were accompanied by a 3 cm greater increase of waist circumference over the period of observation.

Mortensen et al. (2008) followed 4596 middle-aged men and women for 13 yr. The BMI consistently predicted becoming sedentary over this period, but sedentary lifestyle did not predict changes in BMI, unless concurrent changes in physical activity were taken into account.

Myers et al. (2017) monitored 71 adults by means of a Sense-wear arm-band for one week. Sedentary behaviour proved to be positively correlated with both fat mass and waist circumference.

Qi et al. (2012) reported that the genetic predisposition to obesity in 7749 women and 4564 men was enhanced in those reporting extensive television watching.

Raynor et al. (2006) noted that after controlling data for physical activity and diet, both initial television viewing and increases in viewing time were associated with the one-year gain of body mass among 1422 registrants in the US weight control registry.

Staiano et al. (2018) used an accelerometer to assess sedentary time in 71 non-obese adults initially aged 20-35 yr. A high sedentary time was associated with baseline obesity, but sedentary time did not predict future obesity over a 2-year follow-up. Vioque et al. (2000) evaluated television-viewing habits in 814 men and 958 women. The odds ratio of obesity among those who spent more than 4 hours per day watching television was 2.38 relative to those who spent less than 1 hour per day in this fashion.

In summary, the tendency of a person to sedentary behaviour has usually been assessed by the hours per week spent watching television. In children, 4 of 6 such reports showed an association between sedentary behaviour and the development of obesity, although in one of these it was thought that the underlying mechanism was associated snacking rather than sitting. One of the 2 negative reports covered a period of only 12 weeks of observation. In adults, 10 of 13 associations between obesity and television viewing were positive (although one was only positive in women). Of the remaining 3 reports, two found an association at baseline, but not in longitudinal studies, and in the final study, sedentary behaviour was associated with obesity, but this was thought to occur only because sitting had negative effect upon the individual's weekly involvement in physical activity.

## Accumulation of body fat with modernization of the Indigenous lifestyle

Over the past several decades, numerous indigenous communities around the world have experienced dramatic decreases in their habitual physical activity, as they have shifted from a hunter-gatherer lifestyle and have become acculturated to the sedentary habits of current western civilization. The changes of body composition seen in various previously very active populations have been detailed elsewhere (Shephard and Rode, 1996). For our present purpose, it suffices to look at the Inuit community of Igloolik, on the Arctic coastline of Canada, a small settlement where the social and biological changes occurring from 1970 to 1990 have been examined in considerable detail.

In 1970, many of the Inuit people living in the vicinity of Igloolik had recently moved from traditional igloos and temporary summer hunting camps into rows of small pre-fabricated houses, built within the confines of a village. The size of the settled population quickly rose to some 1000. Nevertheless, during the early 1970s many of those occupying the new housing were still living largely off the land, incurring energy expenditures as high as 16 MJ/day during long-distance hunting and gathering expeditions. The settling of the region's population in a single hamlet allowed provision of a K-12 school, a nursing station and a police service. However, the concentration of so many people in a single hamlet quickly depleted regional supplies of game, and most of the local people were obliged to abandon their traditional lifestyle, purchasing food at the village store. They experienced a drastic decline in daily energy expenditures as they curtailed their hunting expeditions, and this change of lifestyle was marked by a substantial drop in aerobic fitness, with an accumulation of body fat (Table 10). The increase in body fat content was documented not only as an increase in the average thickness of standard skin-folds, but also by changes in estimates of body fat content based on underwater weighing and the dilution of doubly-labeled water. However, because the decreased energy expenditure led to a substantial loss of lean tissue, fat accumulation was less obvious in terms of an increase in the body mass index.

Data accumulated during the acculturation of this community offers yet one more proof of an association between a decrease in habitual physical activity and an accumulation of body fat. Nevertheless, interpretation must remain cautious, since a part of the responsibility for the altered body composition may also lie in the transition from "country" to shop food, and other more general consequences of adopting a modern western lifestyle.

**Table 10: Changes in skin-fold thickness, body mass index and aerobic fitness of Igloolik Inuit from 1970 to 1990, as the community transitioned from a hunter-gatherer to a modern settled lifestyle (based on data of Shephard and Rode, 1996).**

| Age group (yr) | Men (1970) | Men (1990) | Women (1970) | Women (1990) |
|---|---|---|---|---|
| | Average thickness of 3 skin-folds (mm) | | | |
| 20-29 | 5.5 | 7.1 | 8.5 | 12.0 |
| 30-39 | 6.3 | 8.4 | 9.2 | 13.5 |
| 40-49 | 5.4 | 10.1 | 7.0 | 16.4 |
| 50-59 | 7.9 | 8.6 | 19.0 | 11.2 |
| | Body mass index (kg/m$^2$) | | | |
| 20-29 | 24.4 | 23.8 | 23.2 | 23.1 |
| 30-39 | 24.9 | 25.8 | 23.9 | 25.4 |
| 40-49 | 25.3 | 26.9 | 23.7 | 27.9 |
| 50-59 | 2f5.8 | 26.4 | 27.5 | 24.0 |
| | Maximal oxygen intake (mL/[kg.min]) | | | |
| 20-29 | 58.4 | 51.1 | 48.1 | 41.0 |
| 30-39 | 55.5 | 46.0 | 46.3 | 35.2 |
| 40-49 | 51.6 | 41.5 | 40.8 | 30.7 |
| 50-59 | 41.6 | 35.2 | 36.4 | 27.7 |

## Randomized controlled trials of physical activity in the prevention of obesity

In principle, randomized controlled trials should offer the clearest measure of the efficacy of physical activity as a means of preventing obesity. There have already been many published trials looking at this question on people of all ages from early childhood to old age, but sometimes studies have been relatively short-term in nature, and often the primary objective has been to treat established obesity rather than to prevent its appearance. In such investigations, there have commonly been accompanying dietary restrictions, leaving unclear the relative contributions of physical activity and dieting to any observed benefits (Thivel et al., 2019).

## Randomized controlled studies on children

Numerous investigators have used randomized controlled trials to look at the efficacy of exercise programmes as a means of preventing the development of obesity in children. However, all too often the increase of physical activity actually achieved has been disappointingly small and/or the follow-up period has been only a few weeks. It is thus hardly surprising that many of these investigations have seen little impact upon the body composition of participants. Where diet has not been controlled, it is also likely that children have chosen to compensate for any added activity simply by eating more. Moreover, BMI has commonly been adopted as the criterion of obesity, with a strong potential for the masking of beneficial effects in the active arm of a trial because of an increase in their lean tissue mass. Further, if an increase of physical activity has been coupled with substantial dietary restrictions, it has been impossible to discern the relative impact of the two components of treatment. Finally, some studies have recruited relatively few obese students, thus limiting the potential for a favourable programme response to develop.

One systematic review (McGovern et al., 2008) found that 17 randomized controlled trials of increased physical activity involving children had yielded inconsistent results, with on average no significant decrease of BMI in the intervention group relative to controls; however, this may simply be because there was an increase of lean tissue mass among the individuals who increased their habitual physical activity. More importantly, the experimental groups showed a significant decrease of fat mass (an average of 0.52 kg, 95% confidence limits -0.30-0.73 kg). Beneficial effects were generally greater when there had also been dietary restrictions and parental involvement in changing the child's lifestyle.

Another meta-analysis (Harris, Kuramoto, Schulzer, and Retallack, 2009) identified 18 trials involving physical activity programmes for children, but in 15 of the 18 studies there had been some type of co-intervention, usually dietary. Observations had continued for 6 months to 3 yr, but no consistent advantage of BMI had been seen in the experimental group relative to control students. Ten of these studies included more direct indices of body composition than BMI measurements, for instance skin-fold readings or estimates of body fat content, but in only 3 of these 10 trials was an advantage of body composition seen in the supposedly more active group. Moreover, in investigations where objective measures of increases in physical activity such as pedometer step counts or accelerometer data were obtained, the experimental group was often found to be taking little more physical activity than those who had been assigned to the control group.

A third meta-analysis found a total of 30 studies involving 145,326 children, with accelerometer records of the physical activity attained in 6153 of these subjects (Metcalf, Henley, and Wilkin, 2012). This report again found that overall, only negligible increases in moderately vigorous and vigorous physical activity were achieved in the intervention groups (at most, an additional 4 min walking or running per day). The authors of this review suggested several possible explanations for the failure to augment physical activity: the programme delivery may have been poor or of insufficient intensity, it may not have been well accepted by the students, or it may simply have replaced other pre-existing forms of physical activity of similar metabolic intensity. In any event, it was not surprising that with no change in habitual activity, few significant changes of body composition were observed.

Other systematic reviews have found little benefit from most childhood anti-obesity programmes (Kameth et al., 2008). Janssen and LeBlanc (2010) underlined the problem that most of the published interventions provided the experimental students with far too little additional physical activity. For health benefits, the minimum effective dose was at least 60 min/d of moderately vigorous physical activity, and where possible an increase to several hours per day should be facilitated.

In reviewing individual studies, it is thus useful to distinguish those that failed to achieve a significant increase of physical activity and/or physical fitness from those that were successful in this regard (Tables 11 and 12).

**Studies where physical activity was either not measured or was not substantially increased.**

Bäcklund et al. (2011) examined the efficacy of a family-based lifestyle programme in a sample of 105 overweight or obese children aged 8-12 yr. The impact of the programme upon habitual physical activity was evaluated by a Sense-wear arm-band. The intervention led to a decrease rather than an increase of daily step count, and there was no change of screen viewing time, so not surprisingly there was also no inter-group difference of BMI at the end of 2 yr.

Coleman et al. (2005) evaluated 744 primary school children initially aged ~8.3 yr. A three-year programme of nutritional information and enhanced physical education yielded some improvement of times on a one-mile run, but the average BMI and waist-hip ratios remained essentially as in the control students. Moreover, by the end of the programme, the time spent on vigorous physical activity differed only marginally between experimental and control students. The one favourable trend in body composition was the finding of a smaller proportion of overweight children in the experimental group.

Fitzgibbon et al. (2011) evaluated a teacher-administered weight control programme in a group of 818 "black" children initially aged ~4.5 yr. After 14 weeks of intervention, there was a 7.5 min/d increase of moderately vigorous physical activity and a 28 min/d decrease of screen viewing time in the experimental group, but this had no significant effect on the BMI Z score relative to control students.

Gentile et al. (2009) adopted a multi-phasic campaign to increase physical activity, reduce screen-viewing times and improve diet. A group of 323 students initially aged ~9.6 yr were allocated between experimental and control groups. The experimental programme induced a small increase of step count at 6 months (an increase of 380 steps/day), with some reduction of screen-viewing time (1.3 h/week according to the students, 1.8 h/week according to their parents), but the BMI of the intervention group remained closely similar to that of the control students.

Hopper et al. (2005) instituted a family fitness and nutritional programme, evaluating the efficacy of this initiative on a sample of 238 grade 3 students. At the end of 20 weeks, the experimental group showed some benefits in terms of both a smaller increase in BMI (a change of +0.32 versus + 0,75 $kg/m^2$ in the controls) and skin-fold thicknesses also increased a little less (an average of +1.13 mm in the experimental group versus +1.30 mm in the controls). The experimental group also showed a small improvement in their times over a 1-mile run, but so did the control group. No formal assessment was made of the extent of changes in physical activity induced by the experimental programme.

Hughes et al. (2008) evaluated a "best practice" behavioural approach in 134 overweight children, aged 5-11 yr. The intervention group received family-centred counseling on physical activity, nutrition and methods of avoiding sedentary behaviour. Evaluation at 6 and 12 months showed the experimental group with only a small advantage over the controls in terms of a smaller decrease in light physical activity (-0.5% versus -3.8%) and a smaller increase in sedentary behaviour (+0.05% versus +4.5%), with no significant inter-group difference of BMI.

Kipping et al. (2008) attempted to adapt an American obesity reduction programme to English schools. Teachers were asked to teach 16 classes on physical activity, nutrition, and methods of reducing sedentary time over a 5-month period, in a trial that involved 472 children aged 9-10 yr. At the end of the 5 months, there was a small trend to a statistically insignificant reduction of screen-viewing time in the experimental students (an average reduction of about 11.6 min/d on weekdays), and a greater likelihood of using active methods of transportation to travel to and from school, but there were no inter-group differences of BMI or the prevalence of obesity.

Klesges et al. (2010) evaluated an obesity prevention programme in 303 African American girls initially aged 8-10 yr. The experimental students received dietary and physical activity counseling at the local YWCA, but after 2 yr they did not differ significantly from control students in terms of either their habitual physical activity or their BMI.

Luepker et al. (1996) made an analysis of the "CATCH" multi-phasic nutritional and physical activity programme, conducted in grades 3 through five at 28 schools. The vigorous physical activity of the intervention group was increased by 8 min per day relative to controls, but the total amount of daily physical activity showed no inter-group difference, and at the end of 3 yr the intervention had produced no favourable changes in BMI or skin-fold readings.

Lohman et al. (2003) focused upon 1368 American Indian children who were initially enrolled in Grade 2. The experimental students participated in a multi-phasic obesity prevention programme, but over a 3-year follow-up they showed little difference in the increase of skin-fold thicknesses (+6.1 vs. 6.4 mm) or in bioimpedance estimates of body fat relative to controls (+5.7 versus +6.1% body fat). The impact of the programme upon daily physical activity does not seem to have been measured.

Marcus et al. (2005) studied 3135 Swedish children in Grades 1-4. A half of the sample underwent a dietary intervention, and participated in an additional 30 min/d of physical activity while they were at school. However, after 4 yr, neither BMI nor total physical activity showed any inter-group difference. The only possible gain from the intervention was some reduction in the number of students in the experimental group who were classed as obese.

Neumark-Sztainer et al. (2003) involved 9th-12th grade girls in a programme that offered 4 additional physical activity sessions per week, together with nutritional guidance. After 16 weeks, data were compared with students who had received only written information on physical activity and nutrition. No significant inter-group differences in BMI or physical activity were seen as a result of this intervention.

Pangrazi et al. (2003) compared a combination of lifestyle activities and physical education with either lifestyle activities alone or no treatment in a sample of 600 4th grade students initially aged ~9.8 yr. Increases of pedometer counts of ~ 1500 steps/day were seen in both of the intervention groups. The study only lasted 12 weeks, and no significant effect on BMI was seen over this period.

Pate et al. (2005) sought to augment habitual physical activity in high-school girls by an improvement in the physical education curriculum. In a sample of 2744 girls initially aged ~13.6 yr, questionnaires suggested that at one year experimental students had made only minor changes in their habitual physical activity, and in consequence there was little difference in the prevalence of obesity between experimental and control girls.

Reed et al. (2008) introduced a 16-month "Active School" model to British Columbian students initially aged 9-11 yr. After 16 months, the intervention group showed only minor changes in their habitual physical activity, and the BMI did not differ between experimental and control groups. However, perhaps because of practice effects, the shuttle-run score was improved for the experimental group.

Reilly et al. (2006) introduced three 30-minute physical activity sessions per week into the programme of pre-school nurseries where the average age of the children was ~4.2 yr. Accelerometer data showed no greater physical activity and no greater reduction of sedentary behaviour in the experimental students than in the controls at 6 or 12 months, and no inter-group differences of BMI Z scores developed. However, the experimental group did have some final advantage over the controls in terms of enhanced motor skills.

Sahota et al. (2001) involved half of a group of 636 primary school students in a healthy eating and lifestyle intervention, while the remaining students followed the normal school curriculum. At the end of 1 year, they saw no changes of physical activity or of sedentary behaviour as a result of the intervention, and there were no final inter-group differences of BMI between the intervention and the control group.

Sallis et al. (2003) attempted to change the eating habits and physical activity patterns of students who were attending 12 of 24 Middle Schools in San Diego, California. At the end of 2 yr, they unfortunately found no significant changes in either habitual physical activity or sedentary time in the intervention group, and not surprisingly there were also no changes of BMI relative to students attending control schools.

Seo et al. (2019) involved 103 obese children and adolescents in the evaluation of a multi-disciplinary exercise programme. At 16 weeks, the exercised students showed favourable Z scores with respect to both BMI and skin-fold thicknesses. The programme also had favourable effects upon cardio-metabolic risk factors, and increased lean tissue mass and muscular strength. However, daily physical activity levels were not measured, and the heart rate following a simple step test remained similar to that seen in the control group.

Taylor et al. (2007) recruited 730 children initially aged 5-12 yr to a trial of a community-based obesity prevention programme. The experimental students received a community-based nutritional programme and the opportunity to participate in a number of physically active events such as walks out of school, although no formal measures of total daily physical activity were made. At the end of 2 yr, the BMI of the experimental students had a lower Z score than that of controls (-0.26), and the average waist circumference was also 1 cm less, but there was no inter-group difference in the prevalence of obesity, suggesting that the programme may have been helpful to those who were not obese, but was less useful to those who were already overweight or obese.

Wafa et al. (2011) tested the impact of 8 hours of group advice on physical activity and nutrition over a 26-week intervention in a group of 107 obese children aged 7-11 yr. After 6 months, the experimental group showed no advantage over controls in terms of BMI or accelerometer measures of habitual physical activity.

Wake et al. (2009) attempted to improve the health behaviours of 258 obese schoolchildren aged 5-10 yr by a brief period of physician counseling. After 6 months, the experimental group showed no advantage relative to controls in terms of BMI or habitual physical activity as monitored by an accelerometer. Another study by the same research group (McCallum et al., 2007) examined the effects of 4 physician consultations on a sample of 2112 obese children initially aged 5-10 yr; it also found no significant differences between experimental and control students at 9 and 15 months.

Webber et al. (2008) endeavoured to increase the physical activity of a half of a sample of 5510 middle-school girls over a 2-year intervention. Their efforts, as assessed by accelerometry, were largely unsuccessful, with the average duration of moderately vigorous physical activity exceeding that of the control group by only 1.6 min/day. It is thus not surprising that they observed no final inter-group differences of BMI, triceps skin-fold thicknesses or aerobic fitness.

**Studies where physical activity was increased substantially.**

Carrell et al. (2005) undertook a randomized 9-month trial in 58 overweight middle-school children initially aged ~12.5 yr. In the experimental subjects, the standard school gymnastics classes (five 45-minute classes every 2 weeks) were replaced by lifestyle, fitness-oriented instruction, with more individual attention to ensure the active involvement of all students. The revised classes also provided the children with some dietary information. After 9 months, the intervention group showed a larger decrease of body fat than controls (respective dual energy x-ray absorptiometry estimates of 4.1% versus 1.9%), and treadmill measures of maximal oxygen intake showed the experimental students having a substantial advantage over the controls (gains of 2.7 versus 0.4 ml/[kg.min]).

Donnelly et al. (2009) implemented a programme designed to increase habitual physical activity and diminish overweight in students attending a half of 28 elementary schools (grades 2 and 3). Over a 3-year period, there was a substantial gain of daily physical activity at an intensity >4 METs in the experimental schools (26 min more than in control students), but nevertheless there was no significant inter-group difference in the final BMI values.

Goldfield et al. (2006) carried out a short-term (8-wk) trial of open-loop reinforcement in a sample of 30 overweight or obese children aged 8-12 yr. The experimental group wore a pedometer throughout the trial, and daily readings provided feedback to students on whether they were meeting prescribed daily physical activity targets. Those taking the required volume of exercise were rewarded with permission to watch television. The process yielded a substantial increase in the daily volume of moderate and vigorous exercise relative to control students (respective durations of moderately vigorous physical activity (23.8 versus 12.3 min/d), and of vigorous physical activity (9.3 versus 4.3 min/d). Moreover, despite the short-term nature of the trial thee significant differences of the change in BMI between experimental and control students (-0.6 versus + 0.3 kg/m$^2$).

Kain et al. (2004) evaluated a combined dietary and physical education programme in Chilean schoolchildren initially aged ~10.6 yr. At a 6-month follow-up, there were small but statistically significant favourable changes for the boys in the experimental group (BMI change relative to controls over the 6 months, 0 versus 0.3 kg/m$^2$, waist circumference change - 8 mm versus +9 mm), but the girls showed no benefits from following the experimental regimen. Physical activity was not measured, but both boys and girls in the experimental group showed significant improvements of shuttle-run score over the trial.

Kriemler et al (2010) recruited 509 Swiss elementary school students to a clustered randomized controlled trial. The intervention group had their standard 3 physical education classes per week up-graded, and supplemented by 2 additional physical activity classes, while the parents of children at control schools were not informed of any changes in the school curriculum. After one year, students at the intervention schools showed some advantages in terms of physical activity as measured by accelerometry (they took 9 min/d more moderately vigorous physical activity than controls), and they also had a greater aerobic fitness as assessed by a shuttle-run test (a Z score of 0.17 relative to controls). Moreover, the average of 4 skin-folds (Z score -0.12), BMI and waist circumference also showed benefits relative to controls.

Lazaar et al. (2007) enhanced primary school physical education by the introduction of two 60-minute specialist-taught sessions per week (where heart rate recordings showed effort at 70% of peak heart rate for at least 42 min per class). In a sample of 425 children aged 6-10 yr, a controlled study showed positive changes in the experimental group. For the boys, the BMI Z score decreased by 2.8%, versus +1.5% in controls. For the girls, BMI Z values were -6.8% versus -2.4%, and waist circumferences also decreased in the experimental students (-3.3% versus +2.8%).

Owens et al. (1999) demonstrated that it is quite practicable to involve 7-11 year-old primary school students in a vigorous physical training programme demanding an additional 4 MJ of energy expenditure each day. Dividing a sample of 79 children between experimental and control groups, the former decreased their body fat content by 2.2% relative to the controls over a 4-month study, at the same time increasing their lean tissue mass by 6.1%.

Patrick et al. (2006) involved a half of 878 adolescents initially aged 11-15 yr in an office- and home-based physical activity and counseling programme. At one year, there was a significant reduction of sedentary behaviour, averaging 1.1 hr/day in both girls and boys from the experimental group, and the boys from this group also reported more physically active days per week, but there was no inter-group difference in the final BMI values. The one other positive effect of the intervention was some improvement in dietary choices by those in the experimental group.

Peralta et al. (2009) completed a small trial on 33 Grade 7 boys. A fitness improvement programme involved one 60-minute in-class session and two 20-minute lunch time sessions of physical activity each week. At 6 months, the students in the experimental group showed several advantages relative to control students (BMI -0.2 kg/m2; body fat -1.7%, waist circumference -1.7 cm). Physical activity was not measured, but boys from the intervention group also had an improved shuttle-run score, and a decrease in reported screen-viewing time.

Puder et al. (2011) studied a group of 652 predominantly migrant Swiss pre-school children initially aged ~5.1 yr. At a half of the nurseries for these children, a multi-disciplinary nutritional and physical activity programme was instituted. Physical activity was not measured as such, but after 10 months, children assigned to the experimental group showed a 1.1% decrease of body fat and a 1 cm decrease of waist circumference relative to controls. The experimental students also showed a greater improvement in shuttle-run scores, but there were no final inter-group difference of BMI, underlining the fallibility of relying upon this measurement as an index of body fatness.

Rodearmel et al. (2006) developed a family-based programme to increase physical activity. Experimental children showed substantial gains of pedometer count (1707 steps/ day in the girls, 1879 steps/day in the boys) at 13 weeks, and this was accompanied by favourable changes in both BMI (-0.65% in experimental students, versus +0.47% in controls) and body fat content (-0.51% in experimental student, versus + 0.91% in controls). However, beneficial changes in body composition were largely confined to the girls in the trial, with little change in the boys.

Simon et al. (2008) organized a programme to increase the popularity of physical activity through debates, social support and attractive exercise options in a group of 954 middle-school students initially aged 12 yr. The experimental group had an appreciable advantage of BMI over control students after both 3 and 4 yr (0.29 and 0.25 kg/m$^2$ respectively), with a parallel decrease in body fat Levels (-1.19%, 0.55%). The intervention group also had higher physical activity levels and reduced screen-viewing times. Those students in the experimental group who were initially obese showed a decrease of BMI at 2 yr, but this benefit did not persist through to 4 yr of observation.

Vandongen et al. (1996) compared various fitness and nutrition programmes in 1147 children aged 10-12 yr. At 9 months, both sexes showed gains on the shuttle run and distance run in response to fitness and fitness plus nutritional interventions. However, there were no changes of BMI, and only the boys pursuing the fitness plus nutrition option showed a 0.7% decrease of body fat content.

Vizcaíno et al. (2008) supplemented the normal 3 sessions/week physical education programme of Spanish students initially aged ~9.4 yr by three 90-minute after-school sport and physical activity programmes, thus causing a substantial increase in the child's total daily physical activity as verified by accelerometer counts. At 24 weeks, body fat levels in the experimental group had decreased by 0.4% in the boys and 0.6% in the girls, but the BMI in both sexes remained comparable with that of the control group.

Weintraub et al. (2008) carried out a small-scale trial evaluating an after-school team-sports programme in 21 obese children from Grades 4 and 5. They noted that experimental students showed improved Z scores for BMI after 6 months (-0.48), and they also undertook more moderate and vigorous physical activity than students in the control group (significantly so at 3 months but not at 6 months).

In summary, Tables 11 and 12 confirm the conclusions from several earlier meta-analyses, namely that many investigators failed to induce or to sustain any substantial increase of physical activity in those students who were assigned to the experimental arm of their studies (Magnusson, Sigurgeirsson, Sveinsson, and Johansson, 2011), and they thus failed to cause any favourable change of body composition in experimental students by the end of their investigation. In Table 11, 20 of 24 trials showed no effect of interventions upon the body composition of experimental subjects, in 2 studies there was a slight improvement in data for the intervention group and in the final two investigations the benefit in experimental subjects was more definitive.

In contrast, among those reports where a significant increase of physical activity was demonstrated, 13 of 15 studies showed a beneficial change of body composition in response to the intervention, and only 2 investigators observed no significant change. This underlines the importance of an effective physical activity intervention if there is to be a measurable loss of body fat. A meta-analysis involving 32,109 students across 32 randomized controlled trials (Sobol-Goldberg, Rabinowitz, and Gross, 2013) concluded that school-based programmes were mildly effective in reducing BMI. The largest effects were seen with programmes that had persisted for a year or more. Other characteristics of effective programming were provision of guidance to the students on ways to improve on both physical activity and nutrition, a behavioural component to the intervention, attempts to change attitudes and monitor the individual's behaviour, modification of the child's environment to favour physical activity, and involvement of the parents, coupled with specific efforts to increase physical activity and improve diet. This analysis concluded that comprehensive and long-term programmes with parental involvement were likely to reduce the BMI by an average of 0.39 $kg/m^2$. A Cochrane analysis further concluded that whether childhood obesity was tackled through the schools or at home, the best results were obtained from a combination of increased physical activity, healthy eating and an improvement of self-image (Waters et al., 2011).

## Randomized controlled studies in adults

Initiatives for the prevention of obesity in adults have often taken the form of initial counseling or written advice rather than involvement in specific exercise programmes, and some of the groups studied have been rather specialized (for example, pregnant women, people with type 2 diabetes mellitus, pre-menopausal women, and schizophrenics where the tendency to sedentary living was enhanced by the use of psycho-depressant drugs).

One systematic review and meta-analysis concluded that an increase of physical activity alone was an effective tactic to improve the body composition of adults, and that the best form of exercise for inducing such a response was a substantial regular volume of moderate or vigorous aerobic activity (Vissers et al., 2013).

**Table 11: Randomized controlled trials evaluating the efficacy of exercise programmes in preventing the development of obesity in children. Findings are summarized for those studies where changes in habitual physical activity were either not measured or were not substantially increased over the study.**

| Author | Subjects | Intervention | Findings | Comments |
|---|---|---|---|---|
| Bäcklund et al. (2011) | 105 overweight & obese children initially aged 8-12 yr | Lifestyle programme vs. controls | No significant difference of BMI at 2 yr | No significant difference of Sense-wear physical activity at 2 yr |
| Coleman et al. (2005) | 744 children initially aged ~8.3 yr | Improved physical ed. and dietary programme | 2 yr follow-up. No effect on average BMI or waist-to-hip ratio (although fewer overweight children in experimental group) | Changes in moderate-to-vigorous and vigorous physical activity small. Some gains in one mile run speed for intervention group |
| Fitzgibbon et al. (2011) | 818 "black" children aged ~4.5 yr | Teacher-administered weight control programme | At 14 weeks, exp. group show 7.5 min/day more moderate-to-vigorous physical activity, 28 min/d less screen time | No significant effect of intervention on BMI Z score |
| Gentile et al. (2009) | 1323 students initially aged ~9.6 yr | Multiphasic physical activity & nutritional programme | At 8 months, experimental students show small increase in step count (380 steps/d), screen time reduced by1.3-1.8 h/wk. | No inter-group difference of BMI |
| Hopper et al. (2005) | 238 third grade students | Family fitness and nutritional programme | 20 week intervention, slight benefits of BMI (+0.32 vs. +0.75 kg/m$^2$) and skin-folds (+1.13 mm vs. 1.31 mm) | Experimental group also had faster final times over 1 mile run |
| Hughes et al. (2008) | 134 overweight children aged 5-11 yr | Best practice behavioural treatment vs. usual care | No difference of BMI from control group at 6 or 12 months | Small decrease in sedentary behaviour, increase in vol. of light physical activity |
| Kipping et al. (2008) | 472 children aged 9-10 yr | 16 lessons on physical activity, nutrition and reducing screen time over 5 months | At 5 months no diff. of BMI or prevalence of obesity in intervention group | 11.6 min/d decrease of screen time in intervention group |
| Klesges et al. (2010) | 303 African-American girls aged 8-10 yr | YWCA counseling to improve nutrition and increase physical activity | At 2 yr, experimental group shows no difference from controls in BMI or physical activity | |
| Loepker et al. (1996) | 28 schools, grades 3 through 5 | Multi-phasic nutritional and physical activity intervention | No difference of intervention group from controls on BMI or skin-folds over 3 yr | 8 min greater vigorous physical activity but no difference of overall physical activity from controls |

**Table 11 Continued**

| Author | Subjects | Intervention | Findings | Comments |
|---|---|---|---|---|
| Lohman et al. (2003) | 1368 American Indian children initially in Grade 2 | Multi-phasic obesity prevention programme | 3-yr follow up, marginal advantage to experimental group (skin-folds +6.1mm vs.+6.4 mm; bio-impedance body fat+5.7% vs. +6.1% ) | |
| Marcus et al. (2005) | 3135 children in grades 1-4 | Dietary intervention, in-school physical activity program, 30 min/d | BMI and physical activity did not differ between exp. and control students at 4 yr | Prevalence of obesity reduced in exp. Group |
| McCallum et al. (2007) | 2112 obese children aged 5-10 yr | 4 physician consultations over 12 weeks | No change of BMI or physical activity relative to controls at 9 and 15 months | See also Wake et al. (2009) |
| Neimark-Sztainer et al. (2003) | 201 9th-12th grade females aged 15 yr | 4 physical activity sessions/wk + 16 wks nutritional guidance vs. written information on physical activity and nutrition | No change of BMI at 16 weeks | |
| Pangrazi et al. (2003) | 600 4th grade students aged 9.8 yr | Lifestyle activities + physical education vs. lifestyle activities alone vs. control students | Small increases of pedometer counts in both experimental groups, but no significant effects on BMI | Study only lasted 12 weeks |
| Reed et al. (2008) | 268 children aged 9-11 yr | "Active School" model | At 16 months, only minor increase of physical activity, no difference of BMI from controls | Shuttle-run score improved in intervention group |
| Reilly et al. {2008) | 545 pre-school children initially aged ~4.2 yr | Three 30 min physical activity sessions/wk in nursery for 24 wk | At 6 and 12 months, no increase of physical activity on accelerometer, no diff. of BMI Z score | Improvement of motor skills in exp. Group |
| Sahota et al. (2001) | 636 primary students initially aged ~8.4 yr | Lifestyle education programme in schools (healthy eating and PA) vs. normal curriculum | No difference of BMI over 1 yr | |
| Sallis et al. (2003) | 24 middle schools in San Diego CA | Measures to improve nutrition and physical activity in experimental schools | Over 2 yr, exp. schools showed no significant advantage of BMI | Physical activity and sedentary time not changed significantly by programme |

**Table 11 Continued**

| Author | Subjects | Intervention | Findings | Comments |
|---|---|---|---|---|
| Seo et al. (2019) | 103 obese children and adolescents | Multi-disciplinary exercise vs. usual care | At 16 weeks, experimental group showed favourable change in Z score for BMI and % body fat | Programme also reduced cardiovascular risk markers, increased lean mass and muscular strength |
| Taylor et al. (2007) | 730 children aged 5-12 yr | Community-based nutrition and physical activity programme | At 2 yr, lower BMI Z score (-0.26) and 1 cm smaller waist circumference in exp. Group | No change in prevalence of obesity |
| Wafa et al. (2011) | 107 obese children aged 7-11 yr | 8 h of group intervention over 26 wk | No advantage of BMI or accelerometer measures of physical activity in exp. group at 6 months | |
| Wake et al. (2009) | 258 obese children aged 5-10 yr | Brief physician counseling | At 6 months, no change of BMI or physical activity (accelerometer) in experimental group | |
| Webber et al. (2008) | 5510 girls from Grades 6 and 8 | 2-yr intervention increased moderate-to-vigorous physical activity by only 1.6 min/day | No change in % body fat (triceps skin-fold, BMI) in experimental group | No change of aerobic fitness |

**Table 12: Randomized controlled trials evaluating the efficacy of exercise programmes in preventing the development of obesity in children; data from studies where the experimental group developed a substantial gain of physical activity and/or aerobic fitness relative to the controls.**

| Author | Subjects | Intervention | Findings | Comments |
|---|---|---|---|---|
| Carrell et al. (2005) | 58 overweight middle-school children | Lifestyle, fitness-oriented gym classes vs. standard school programme. | At 9 months, loss of body fat 4.1% vs. 1.9% in controls | Treadmill maximal oxygen uptake +2.7 vs. +0.4 ml/[kg.min] in controls |
| Donnelly et al. (2009) | Grades 2 and 3 in 24 elementary schools | Programme to increase physical activity | Over 3 yr, no change of BMI relative to controls | Activity >4 METs increased 26 min/d vs. control subjects |
| Goldfield et al. (2006) | 30 overweight or obese children aged 8-12 yr | Feed-back of daily pedometer count, rewards of TV viewing for meeting goals vs. controls | Over 8 wk, experimental group BMI -0.6 vs. +0.3kg/m$^2$ in controls | Moderate-to-vigorous physical activity + 23.8 min/d vs. + 12.3min/d, vigorous physical activity 9.3 vs. 4.3 min/d |
| Kain et al. (2004) | 2141 intervention, 1202 control children initially aged 10.6 yr | Combined dietary and physical activity intervention (90 min physical ed. class, 15 min active recess) | At 8-month follow-up boys BMI change 0.0 vs. +0.3 kg/m$^2$, waist circumference change - 8 mm vs. +9 mm; no significant changes in girls | |
| Kriemler et al. (2010) | 502 elem. school children (aged 7-11 yr) | 5 restructured physical ed. classes/wk. vs. standard programme | At 1 yr, 4 skin-folds show Z score of -0.12, also benefits on BMI and waist circumference in experimental group | Experimental group shows gains on shuttle-run (Z score +0.17), and on accelerometry |
| Lazaar et al. (2007) | 425 children aged 6-10 yr | 2 h additional physical ed./wk (heart rate ~60% max) | At 6 months, boys show BMI Z score -2.8% vs. +1.5%; girls BMI -6.8% vs. -2.4%, waist circumference -3.3% vs. +2.8% | |
| Owens et al. (1999) | 74 obese children aged 7-11 yr | 4 months physical training 5 d/wk, 4 MJ/session | Loss of 2.2% fat relative to controls | Parallel 6.1% increase of lean tissue |
| Patrick et al. (2008) | 878 adolescents aged 11-15 yr | Office- and counseling- based nutrition and physical activity group, vs. sun-protection advised controls | Significant reduction of sed. time (-1.1 h/d) in both exp. girls and boys over 1 yr, but no inter-group diff BMI | Some improvements in dietary choices in experimental group |
| Peralta et al. (2009) | 33 grade 7 boys | One 60 min class and two 20-min lunch-time activities/wk | At 6 months, experimental students show advantage of BMI (-0.2 kg/m$^2$), body fat (-1.7%) and waist circumference(-1.7 cm) | Also improved shuttle run score and reduced screen time vs. controls |

**Table 12 Continued**

| Author | Subjects | Intervention | Findings | Comments |
|---|---|---|---|---|
| Puder et al. (2011) | 652 pre-school children of migrants, initially aged ~5.1 yr | Multi-disciplinary physical activity & nutritional programme | At 10 months, 1.1% decrease of body fat%, 1 cm decrease of waist circumference in experimental group | No inter-group difference of BMI |
| Rodearmel et al. (2006) | 105 families with children 8-12 yr old | Family-based increase of physical activity | At 13 weeks, BMI -0.65% vs. + 0.47% in controls, body fat -0.51% vs.+0.91% | Step count increased 1707/d (girls), 1879/d (boys) in experimental group |
| Simon et al. (2008) | 954 students, initially aged 12 yr | Debates, social support, attractive phys, activity options | At 3 & 4 yrs, exp. students had advantage of BMI (0.29, 0.25 kg/m$^2$) | In obese students, advantage at 2 yr, but did not persist to 4 yr |
| Vandongen et al. (1996) | 1147 children aged 10-12 yr | Various programmes, including fitness with or without nutritional advice | At 9 months, no change of BMI, boys in fitness + nutrition group showed decrease of fat (-0.7%) | Both sexes showed gains on shuttle run and distance run with fitness or fitness + nutrition vs. controls |
| Vizcaíno et al. (2008) | 1044 children initially aged ~9.4 yr | 3 h physical ed./wk supplemented by 3 x 90 min after-school activities | At 24 weeks, body fat decreased by 0.4% (boys) and 0.6% (girls) BUT no change of BMI relative to controls | Increase of physical activity verified by accelerometer |
| Weintraub et al. (2008) | 21 obese children, grades 4 & 5 | After school team sports | Experimental group improved BMI Z scores at 6 months relative to controls | Increased moderate-to-vigorous physical activity, significant at 3 but not at 6 months |

Another review examined data collected over 25 yr, concluding that most studies had focused on the moderately obese, with observations limited to a relatively short time-span. It argued that over 3 months, likely decreases of body mass from dieting, exercise and dieting plus exercise averaged 10.7, 2.9 and 11.0 kg, respectively; when expressed as fat loss per week, the corresponding figures from this review were 0.78, 0.22, and 0.75 kg (Miller, Koceja, and Hamilton, 1997). In terms of the results seen after 12 months, the authors of this review concluded that a combination of dietary restriction and an increase in physical activity was the best option (Miller et al., 1997). However, some recent reports using more vigorous exercise programmes have achieved much better results than this with exercise alone. Verbreggen et al. (2016) reiterated the issue that weight loss was a fallible criterion of fat loss, and in their meta-analysis they underlined that although dieting often produced a greater weight loss than exercise, an increase of daily physical activity had a much greater effect in limiting the accumulation of visceral fat.

In looking at the published material on adults, it is convenient to consider separately articles relating to young and middle-aged adults and findings in the frail elderly (where the ability to increase habitual physical activity may be quite limited).

**Trials in young and middle-aged adults.**

Many randomized controlled trials provide data on the effects of added physical activity upon the body composition of young, middle-aged and older adults, with some reports evaluating the benefits of aerobic exercise of various intensities, others looking at the effects of resistance training, and yet others at a combination of aerobic and resistance training. Randomized comparisons of the three modalities have suggested that combined aerobic and resistance interventions provide the optimum response in terms of body composition (Schwingshackl, Dias, Strasser, and Hoffmann, 2013).

Typically, subjects have been followed for periods of 12-16 weeks, and often sample sizes have been quite small. There still remains a need for large, long-term studies of the efficacy of exercise programmes, looking not only at the immediate response, but also at issues of long-term programme adherence. Many investigators have had the treatment of obesity, diabetes mellitus or hypertension as their primary objective, and in consequence have added an element of dietary restriction to exercise-centred interventions. Several reports have also highlighted the fallibility of BMI as a measure of obesity, noting that other more direct measures of body fat content such as skin-fold thicknesses and waist circumferences are more likely to reveal a beneficial response. Too often, the BMI remains unchanged because the added physical activity has increased the individual's lean tissue mass by an amount that matches the loss of fat.

It is appropriate to separate those trials where the unique effects of exercise can be evaluated from multi-phasic interventions that have included dietary restriction and components of therapy other than an increase of habitual physical activity.

***Multi-phasic therapies.***

Burke et al. (2003) were interested in countering the deterioration of physical condition that sometimes follows marriage, and they carried out a randomized controlled intervention on 137 couples aged 18-62 yr. Their subjects were assigned between a group that received 6 physical activity and nutritional leaflets (a half mailed and a half given at interactive sessions), a group that received the same information without the interactive sessions, and a control group. Fewer people in the first group tended to become obese over the year following their marriage, but inter-group differences were not statistically significant.

Litterell et al (2003) explored the value of attending 16 weeks of weekly psycho-educational modules as a means of preventing drug-induced weight gains in 70 schizophrenic patients aged an average of 34 yr. The experimental group showed benefit in terms of weight change at 6 months (-0.05 kg in the intervention group, versus +4.3 kg in controls, $p = 0.007$).

Mourier et al. (1997) examined the effects of physical training with and without branch-chain amino-acid supplementation in a small 4-group trial of 24 patients aged ~45 yr with diagnoses o non-insulin-dependent diabetes mellitus. The training programme (45 min of cycling at 75% of maximal oxygen intake, 3 times per week for 8 weeks) reduced body fat content, to a greater extent in the abdominal region (48%) than in subcutaneous tissue (18%), but the extent of this response was not influenced by the administration of branch-chain amino acids.

Muto and Yamauchi (2004) offered a 4-day multi-faceted health seminar, coupled with a follow-up self-evaluation, to half of a sample of 302 male Japanese building maintenance workers aged 42-43 yr. Weight changes favoured the intervention group over controls after both 6 months (-1.6 kg versus -0.1 kg), and 18 months (-1.0 versus +0.5 kg).

Polley et al. (2002) followed 120 pregnant women who were first seen before the 20th week of gestation. Some 33% of those who received individualized counseling exceeded the recommended weight gain for pregnancy, whereas this was true in 58% of controls.

Proper et al. (2003) offered written lifestyle information plus seven 20-minute counseling sessions to a half of 299 municipal employees (77% males, average age 44 yr). Despite achieving only a small increase of physical activity with the intervention (an increase from 5.2 to 5.6 units on an arbitrary physical activity scale), after 9 months, the percentage of body fat was significantly lower in the intervention than in the controls (a loss of -1.4%, versus -0.4% in the controls). However, there were no final inter-group differences of BMI.

Simkin-Silverman et al. (2003) undertook a controlled 5-year lifestyle intervention in 535 premenopausal women aged 44-50 yr. The programme began with15 group meetings over the first 6 months, with the aim of increasing energy expenditures by 4-6 MJ/week, and this was accompanied by adoption of a low-fat diet. There was a good adherence to the prescribed regimen, and finally 55% of the intervention group remained at or below their initial weight, whereas this was true of only 26% of the controls. The final weight change for the experimental group averaged -0.1 kg, compared with +2.4 kg in the controls ($p = 0.001$).

In summary, there was an improvement of body composition in all seven multiphasic interventions, although in most of these studies it was difficult to discern the relative contributions to this response of increased physical activity and other components of treatment.

***Evaluations of unique physical activity interventions.***

The report of Avila et al. (2010) underscored the dangers of simply relying on changes of body mass or BMI as a measure of favourable changes in body composition (Table 13). In a sample of 27 overweight adults aged ~67 yr, the investigation compared the effects of 10 weeks of dieting alone versus the response seen when the same dietary regimen was supplemented by regular resistance exercise sessions. The change in body mass at 10 weeks showed no inter-group difference, but the exercised subjects underwent a much greater decrease of body fat than the controls (-4.1 vs. -0.2 kg), and they also gained (+0.8 kg) rather than lost (-1.4 kg) of their lean tissue mass.

**Table 13: Randomized controlled trials evaluating the efficacy of exercise programmes in preventing the development of obesity in adults.**

| Author | Subjects | Intervention | Findings | Comments |
|---|---|---|---|---|
| **Multi-phasic interventions** | | | | |
| Burke et al. (2003) | 137 couples aged 18-62 yr | Leaflets on physical activity and nutrition, plus interactive sessions vs. leaflets alone vs. no treatment for 4 months | No significant inter-group differences in BMI or waist/hip ratios | Trend to less obesity in first group |
| Litterell et al (2003) | 70 schizophrenic patients aged ~34 yr, receiving drug treatment. | Weekly psycho-educational modules for 16 wks | Weight change at 6 months -0.05 kg vs. +4.3 kg (controls) | |
| Mourier et al. (1997) | 24 patients with non-insulin dependent diabetes mellitus, aged ~45 yr | Training + BCAA, training + placebo, Sedentary + BCAA, sed. + placebo | Training decreased body fat (abdominal 48%, subcutaneous 18%) | Branch-chained amino acid (BCAA) supplements had no effect |
| Muto & Yamauchi (2004) | 302 male building maintenance workers aged 42-43 yr | 4-day health seminar & follow-up self-evaluation every 3 months | Body mass change at 6 months (-1.6 kg vs. -0.1 kg), 18 months (-1.0 kg vs. 0.5 kg) | 2.5 kg increase of lean mass, no change of body mass relative to controls |
| Polley et al. (2992) | 120 pregnant women aged >18 yr, fist seen <20 weeks gestation, normal initial weight | Individual counselling | 33% of intervention group exceeded recommended weight gain, 58% of controls did so | No effect on post-partum weight loss |
| Proper et al. (2003) | 299 municipal employees (77% male), aged ~44 yr | Written lifestyle information plus seven 20-min counseling sessions vs. control | % body fat significantly different at 9 month follow-up (-1.4% vs. -0.4%), but no inter-group difference in BMI | Very small increase of physical activity achieved (activity index 5.6 vs. 5.2) |
| Simkin-Silverman et al. (2003) | 535 premenopausal women aged 44-50 yr | 5-yr lifestyle intervention; 15 group meetings over 6 months to increase energy expenditure by 4-6 MJ/wk, low fat diet | 55% of intervention group at or below initial weight, vs. 26% of controls; wt. change -0.1 kg vs. +2.4 kg | Good long-term adherence to physical activity programme |

**Table 13 Continued**

| Author | Subjects | Intervention | Findings | Comments |
|---|---|---|---|---|
| **Unique evaluation of efficacy of physical activity** | | | | |
| Avila et al. (2010) | 27 overweight adults aged ~67 yr | Diet vs. diet + resistance exercise | At 10 wk, resistance ex. gave larger fat loss (-4.1 kg vs. -0.2 kg) | No inter-group difference of total weight loss, lean mass +0.8 kg vs. -1.4 kg |
| Cho et al. (2011) | 45 women aged ~45 yr | High vs. low intensity ex. vs. control | At 12 wk, waist circumference -5.7, -5.5, -0.8 cm. Subcutaneous fat -20, -28, +2 cm$^2$, abdominal fat -7, -20, -2 cm$^2$, | |
| Church et al. (2007) | 464 sedentary post-menopausal women | 3 volumes of exercise (16.6, 33.3, 49.9 kJ/kg per session) vs. controls | At 6 months, all 3 exercise doses showed 3 cm decrease of waist circumference relative to controls | No dietary restrictions, Decrease of total body fat not stat. significant |
| Cuff et al. (2003) | 28 postmenopausal women with type 2 diabetes | Aerobic ex. vs. aerobic + resistance ex. vs. control | At 16 wk, subcutaneous fat -2.0%, -4.7%, +3.2%, visceral fat -4.1%, -10.5%, -0.2% | Glucose regulation better with combined therapy |
| Chomentowski et al. (2009) | 29 overweight or obese adults aged ~ 67 yr | 2-4 MJ/d dietary restriction with or without walking 35-45 min 3/wk | At 4 months fat loss 16.5% vs. 20.7%, fat-free mass -4.3% vs. -1.1% | Added ex. also decreased loss of muscle cross-section |
| Di Pietro et al. (1998) | 16 adults aged ~73 yr | 4-month mini-trampoline training 60 min, 4/wk, intensity rising to 75% max. heart rate vs. yoga | No effect on abdominal circumference or abdominal fat | 16% increase of peak oxygen uptake |
| Donges et al. (2013) | 47 overweight men aged ~48 yr | Endurance ex. vs. resistance ex. vs. combined ex. vs. control | At 12 wk, fat mass -4.5%, -2.8%, -6.1%, +2.4%; subcutaneous fat -4.4%, -4.0%, -4.4%, +1.8%; visceral fat -10.3%, -12.2%, -8.6%, -0.7% | Favourable changes in plasma cytokines and insulin sensitivity with ex. |
| Donnelly et al. (2013) | 141 overweight or obese adults aged ~22.6 yr | Exercise 5 d/wk, 1.6 or 2.4 MJ/session vs. control | At 10 months, wt change ; -3.9, -5.2, +0.5 kg; fat mass -3.5, -5.2, +0.2 kg | No dietary restrictions |
| Friedenreich et al. (2011) | 320 post-menopausal women aged 50-74 yr | 45 min of moderate-to-vigorous aerobic exercise 5 times/wk (179 min/wk) vs. controls | At 1 yr, 2.0 kg fat loss relative to controls | Greater fat loss with greater vol. exercise |
| Ho et al. (2012) | 64 adults aged 40-66 yr | Aerobic ex. vs. resistance ex. vs. combined ex, vs. controls | At 12 weeks, body fat -0.7 kg, -0.4 kg, -1.6 kg, +0.2 kg | |

**Table 13 Continued**

| Author | Subjects | Intervention | Findings | Comments |
|---|---|---|---|---|
| Hurling et al. (2007) | 77 adults aged ~48 yr | Internet-based physical activity programme | Over 9 wk, significant advantage of bio-impedance body fat relative to controls (-2.8% vs.-0.2% | Accelerometer data shows increase of activity in 3-6 MET range |
| Irving et al. (2008) | 27 women aged ~ 51 yr | High vs. low intensity aerobic ex. vs. control | At 16 wk, high intensity ex. reduced visceral, fat, light ex. & control progs. did not | |
| Irwin et al. (2003) | 173 post-menopausal overweight women, aged 50-75 yr | Exercise facility and home-based walking & other forms of mod. exercise vs. exercise vs. controls | 12 months benefits of BMI (-0.3 vs. +0.3 kg/m$^2$), waist circum. -1.0 vs. +0.1 cm), % body fat (-1.2% vs. -0.2%) | Dose-response effect with vol. of exercise performed |
| Jefferson et al. (2016) | 32 obese adults aged ~ 68 yr | 3 d/wk resistance training vs. resistance ex. + 2.5 MJ/d dietary deficit | At 5 months. BMI -0.08 vs. -2.2 kg/m$^2$, waist circumference -1.4 vs. -8.0 cm. body fat -0.2 vs. -3.1 kg | Lean mass +0.1 kg vs. -1.1 kg |
| Jung et al. (2012) | 28 overweight women with type 2 diabetes, age ~ 54 yr | Vigorous or moderate exercise (equi-caloric) vs. control | At 12 wk, waist circumference -2.7% vs. -2.8% vs. +7.2%, total fat area -7.6%, -9.3%, +0.5% | Moderate exercise had more effect on diabetes than equi-caloric vigorous exercise |
| Karstuft et al. (2013) | 32 patients with type 2 diabetes mellitus | Continuous vs. interval walking vs. control | At 4 months, response in interval group only BMI -1.4 kg/m$^{2,}$ body fat (DXT) -3.1kg | Interval group also showed increase of aerobic power (4.4 ml/[kg.min]) |
| Kwon et al. (2010) | 27 obese women, type 2 diabetes | 60 min mod. walking 5/wk vs. controls | At 12 wk, BMI -0.8 vs. -0.1 kg/m$^2$, waist circumference -3.5 vs. -1.0 cm, total fat -37 vs. -5 cm$^2$ | |
| Lehmann et al. (1995) | 29 adults aged 50-60 yr with non-insulin dependent diabetes mellitus | Lab exercise once/wk for 90 min, at 50-70% max. effort, home ex. 3/wk vs. controls | Loss of fat relative to controls, 2.3% at 3 months, 4.3% at 6 months | |
| Marcos-Pardo et al. (2018) | 47 adults aged 67-75 yr | 3 sessions resistance ex./wk vs. control | At 12 wk, -1.4% vs. -0.15% body fat | No inter-group difference of BMI |
| McTiernan et al. (2007) | 202 sedentary adults aged 40-75 yr | Exercise 370 min/wk (men), 295 min/wk (women) vs. controls | At 1 yr, loss of fat mass 3.0 kg (men), 1.9 kg (women) vs. +0.2 kg (controls) | Parallel changes in waist circumference |

**Table 13 Continued**

| Author | Subjects | Intervention | Findings | Comments |
|---|---|---|---|---|
| Messier et al. (2010) | 137 overweight or obese post-menopausal women | Energy restriction (2.0-3.2 MJ/d) alone or with resistance training 3 d/wk | At 6 months, fat loss 3.9 kg vs. 5.3 kg | Exercise component gives large increase in strength |
| Moghadasi et al. (2013) | 16 obese and overweight men aged 35-50 yr | Treadmill run 2 miles in 30 min 4 dd/wk vs. control | At 12 wk, bio-impedance body fat -1.9% vs. no change | Adiponectin mRNA increased |
| Nicklas et al. (2015) | 126 adults aged 65-79 yr | Resistance ex. vs. resistance ex. + diet | At 5 months, 0.6 kg vs. 3.6 kg | Lean tissue +0.3 vs. -1.1 kg |
| Park et al. (2003) | 30 obese women aged 30-45 yr | Aerobic ex. 6 d/wk vs. aerobic (3 d/wk) + resistance ex. (3 d/wk) vs. control | At 24 wk, body mass -4.7, -6.4, +0.6 kg; body fat -9.2, -10.3, 2.3% | |
| Reichkendler et al. (2013) | 61 overweight men aged ~30 yr | 2.4 vs. 1.2 MJ/d exercise vs. control | At 11 wk, fat loss 3.8 vs. 4.2 kg vs 0.1 kg (controls) | Equal loss of subcutaneous and visceral fat |
| Ross et al. (2000) | 52 obese men aged 40-45 yr | Diet vs. exercise with or without wt loss vs. control | At 12 wk ex with wt loss reduced far 6.1 kg, vs. 4.8 kg loss with dieting | Aerobic fitness of ex. group increased 16% |
| Silva et al (Silva et al., 2010) | .239 obese women aged ~38 yr | Autonomous exercise promotion vs. Control | At 12 months, 7.3% weight loss, vs. 1.7% in controls | Physical activity increased 2049 steps/day |
| Slentz et al. (2004) | 120 sedentary overweight adults aged 40-65 yr | High vol., low volume vigorous exercise vs. low vol. mod. exercise vs. controls | At 8 months, 4.8 to 2.5 kg fat loss, vs. +0.4 kg fat gain (controls) | Energy balance can be corrected by walking 30 min/day |
| Vahlberg et al. (2017) & | 43 adults aged 65-85 yr seen 1 yr after stroke | Biweekly progressive resistance & balance exercises vs. control | At 3 months, decrease of body fat (-1.5 vs.+0,13%) | No change of fat free mass |
| Wood et al. (1983) | 81 sedentary men aged 30-55 yr | One yr running programme | -3.8% fat loss, vs.+2.0% gain in controls; max. ox. intake +9.0 vs -1.4 ml/[kg.min] | Minimum 13 km/wk for beneficial changes in HDL cholesterol |
| Yassine et al. (2000) | 25 obese adults aged ~65.5 yr | Exercise 50-60 min/d 5d/wk) vs. exercise + caloric restriction (-2 MJ/d) | At 12 wk, fat loss 4.2 kg vs. 6.0 kg, waist circumference -5.6 cm vs. -6.5 cm | Much larger decrease of BMI with combined treatment |

Cho et al. (2011) compared the efficacy of high intensity exercise (an effort demanding 70-75% of maximal oxygen intake) with an equal volume (1.2 MJ) of low intensity exercise sessions (at 40-50% of maximal oxygen intake) in a sample of 45 women aged ~45 yr. At 12 weeks, the decreases in waist circumference for the 2 exercised groups and for control subjects were 5.7, 5.5 and 0.8 cm respectively. Likewise, subcutaneous fat levels changed by -20, -28 and +2 $cm^2$ and abdominal fat levels by -7, -20 and -2 $cm^2$. In other words, if total energy expenditures were comparable, body fat could be reduced at least as effectively by a low as by a high intensity physical programme.

A small study by Chomentowski et al. 2009) further underlined the importance of exercise to the conservation of lean tissue during the process of fat reduction. A half of 29 overweight or obese adults aged ~ 67 yr were placed on a diet that reduced energy intake by 2-4 MJ/day; in itself, this reduced body fat content by 16.5%. The addition of moderate intensity walking sessions (35-45 min/d 3 d/wk) to this dietary restriction only increased fat less slightly (to 20.7%), but the exercise sessions had the important side-benefit of reducing the loss of lean tissue from 4.3% to 1.1%.

Church et al. (2007) allocated a sample of 464 sedentary postmenopausal women between 3 experimental groups and one control group. The experimental groups increased their daily energy expenditure by 16.6, 33,3 or 49.9 kJ/g per week, without dietary restriction. After 6 months, all 3 exercised groups showed a 3 cm decrease of waist circumference relative to the controls; differences in the total volume of exercise undertaken per week did not seem to influence the magnitude of this response. There was also a trend to a decrease of body fat in all three exercised groups relative to the controls, but this trend was not statistically significant.

Cuff et al. (2093) examined responses in 28 postmenopausal women with type 2 diabetes mellitus. Subjects were divided between aerobic exercise (75 min of low impact work, 3 times per week), aerobic plus resistance exercise (a similar total duration of exercise and a similar total energy expenditure) and a control group. At 16 weeks, the respective changes in subcutaneous fat were -2.0%, -4.7%, and + 3.2%, and changes in visceral fat were - 4/1%, -10.5% and -0.5%. The combined aerobic plus resistance training yielded the largest improvement in blood glucose regulation.

Di Pietro et al. (1998) involved a half of a small group of adults aged ~73 yr in a 4-month trampoline training programme. Sixty-minute sessions of trampoline exercise were held 4 times per week, at an intensity rising from 55% to 75% of the individual's maximal heart rate, while the controls simply participated in a light yoga programme. The aerobic activity did not alter waist circumference or abdominal fat content relative to controls, although it did induce a 16% increase of peak oxygen intake.

Donges et al. (2013) compared the effects of endurance exercise, resistance exercise, and an equally-timed dose of endurance plus resistance exercise relative to controls in 47 overweight men aged ~48 yr. At 12 weeks, the changes in fat mass for the 4 subject groups were -4.6%, -2.8%, -6.1% and +2.4%. Changes in subcutaneous fat were -4.4%, -4.0%, -4.4%, and +1.8% and for visceral fat the corresponding figures were -10.3%, -12.2%, -8.8% and -0.7%. The three exercise options not only improved body composition, but also induced favourable changes of plasma cytokines and insulin sensitivity.

Donnelly et al. (2013) studied 141 overweight or obese young adults, aged ~22.6 yr. Responses to five-day per week exercise programmes with energy expenditures of 1.6 or 2.4 MJ per session, without dietary restriction, were compared with findings for a control group. After 10 months, there were body mass losses of 3.9 kg and 5.2 kg in the two experimental groups, compared with a gain of 0.5 kg in controls, while respective changes in body fat were -3.5 kg, -5.2 kg and +0.2 kg.

Friedenreich et al. (2011) arranged up to five 45-minute sessions of moderate- to vigorous- aerobic activity per week for one year. Their sample comprised 320 postmenopausal and initially sedentary women aged 50-74 yr. At the end of 1 year, the experimental group had lost 2.0 kg of fat relative to control subjects, while essentially undertaking no more than the minimum public health recommended volume of weekly physical activity. In individuals who had engaged in a greater volume of physical activity than this minimum, there was a proportionally greater loss of body fat, this observation being confirmed in a subsequent trial comparing the benefits of 300 versus 150 min of exercise per week (Friedenreich et al., 2015). Coker et al. (2009) also found a greater effect from exercise at 75% rather than 50% of maximal oxygen intake, even though the total added energy expenditure was the same for the two programmes (4 MJ/wk). Clark (2015) further stressed the importance to fat loss of a high intensity exercise programme rather than simply the development of a large negative energy balance.

Ho et al. (2012) divided a sample of 64 adults aged 40-66 yr four ways, between aerobic exercise (30 min per session at 60% of their heart rate reserve), resistance training (30 min per session), both modalities of training (15 + 15 min per session) and a control group. After 12 weeks, the combined training had induced a larger loss of body fat than either of the individual exercise treatments (-1.6 kg vs. -0.7 kg and -0.4 kg).

Hurling et al. (2007) exploited an internet and mobile-phone-based system to encourage greater physical activity in a half of a group of 77 adults aged ~48 yr. Over the course of 9 weeks, accelerometer data showed that the experimental group had increased their volume of physical activity in the 3-6 MET range of intensities, and this response was reflected in a substantial loss in bio-impedance estimates of body fat (-2.8%) compared with the negligible -0.2% change seen in control subjects.

Irving et al. (2008) underlined the importance of including high intensity exercise in any preventive or therapeutic programme. In a sample of 27 women aged ~51 yr, they compared a regimen involving a combination of 3 days of high-intensity aerobic exercise (a score of 15-17 on the "rating of perceived exertion" scale, and progressing to an energy expenditure of 1.6 MJ/session) plus 2 days of light intensity exercise with an iso-caloric programme of 5 days of light aerobic exercise (corresponding to an RPE of 10-12). At 16 weeks, the high intensity regimen reduced visceral fat content, but no change of visceral fat was seen with the light intensity exercise or the control group. On the other hand, there was no inter-group difference in the total loss of body fat.

Irwin et al. (2003) involved 173 overweight postmenopausal women aged 50-75 yr in a trial of moderate exercise, performed both at an exercise facility and at home. Vigorous walking proved the most popular conditioning option. Over 12 months, the intervention group showed an improvement in various measures of body composition relative to control subjects (BMI -0.3 vs. +0.3 kg/m$^2$), waist circumference (-1.0 cm versus. +0.1 cm) and percentage body fat (-1.2% vs. -0.2%). Moreover, the magnitude of these beneficial changes was positively associated with the volume of exercise undertaken by the individual subjects.

Jefferson et al. (2016) examined changes of arterial stiffness in 32 obese adults aged ~68 yr. A half of the group undertook resistance exercise 3 d/wk, and findings for these individuals were compared with data for the remaining subjects, where a 2.5 MJ/d decrease of food intake was imposed. At 5 months, losses of fat were substantially greater in those subjects where dietary restrictions had been imposed (BMI -0.08 vs. -2.2 kg/m$^2$, waist circumference -1.4 cm versus - 8.0 cm, and fat mass -0.2 kg versus -3.1 kg). However, the dietary restriction also increased the loss of lean tissue relative to exercise alone (-0.1 g vs. -1.1 g).

Jung et al. (2012) compared iso-caloric (2 MJ) bouts of vigorous (>5.3 METs for 30 min) and moderate (3.5-5.0 METs) exercise, undertaken for 60 min, 5 times per week in a group of 28 overweight women with type 2 diabetes. After 12 weeks, the waist circumference had decreased by 2.7% with vigorous exercise, and by 0.8% with moderate exercise, but it had increased by 7.2% in the control group. The total fat area had decreased by 7.6% and 9.0% with vigorous and moderate exercise, respectively, but had increased by 0.5% in controls. The moderate exercise regimen had also led to the greatest improvement in glucose tolerance.

Karstuft et al. (2013) conducted a small trial on 32 older adults with type 2 diabetes mellitus. Twelve of this group undertook continuous moderate walking (60 minute sessions, five times per week at 55% of peak aerobic power), 12 undertook interval walking at 70% of peak aerobic power, and the remainder served as controls. Over 4 months, changes of fitness and body composition were seen only in those undertaking the interval training. This group showed an increase of peak aerobic power on the treadmill (4.4 ml/[kg.min]), a decrease of BMI (-1.4 kg/m$^2$), and a 3.1 kg decrease of fat mass, as assessed by dual beam x-ray absorptiometry.

Kwon et al. (2010) evaluated the effects of walking 60 min/d on 5 d/wk, in a group of 27 obese women with type 2 diabetes mellitus. At 12 weeks, the physically active group showed advantageous changes relative to controls in terms of BMI (-0.8 versus -0.1 kg/m$^2$), waist circumference (-3.5 cm versus -1.0 cm) and total body fat (-37 cm$^2$ versus -5 cm$^2$).

Lehmann et al. (1995) demonstrated that a largely home-based exercise programme offered an effective method for the control of obesity in a sample of 29 adults with non-insulin dependent diabetes mellitus, aged 50-60 yr. A half of the group exercised once per week at the laboratory for 90 min at 50-70% of their maximal effort, and they supplemented this activity by home exercise, performed on a further 3 d/wk. This regimen induced a substantial loss of body fat relative to controls (2.3% at 3 months, 3.4% at 6 months), with a 2.5 kg increase of lean tissue mass, although no significant change of overall body mass was seen relative to controls.

Marcos-Pardo et al. (2018) examined the effects of resistance exercise on the body composition of older people, dividing a sample of 47 adults aged 67-75 yr between an experimental and a control group. The experimental subjects undertook 3 sessions of resistance exercise per week, and at 12 weeks they had lost 1.4% body fat, compared with a negligible change of 0.15% in control subjects. Nevertheless, there was no inter-group difference of BMI after the 12 weeks of enhanced activity.

McTiernan et al. (2007) suggested that their data supported consensus recommendations that 60 min/d of moderate to vigorous physical activity was sufficient to prevent and treat obesity. Taking a sample of 202 sedentary adults aged 40-75 yr, the men engaged in 370 min/wk of moderate-to-vigorous facility- and home-based exercise each week, and the women undertook 295 min/wk of such exercise. When evaluated at 12 months, respective decreases in fat mass were 3.0 kg and 1.8 kg relative to controls, and there were parallel improvements in waist circumferences.

Messier et al. (2010) examined 137 overweight or obese postmenopausal women. All were placed on a 2.0-3.2 MJ/d reduction of food intake, and a third of the group also performed resistance exercise twice per week. After 6 months, the addition of resistance exercise had increased fat loss from 3.9 kg to 5.3 kg, and the resistance programme had also substantially increased the muscular strength of participants. Moghadasi et al. (2013) focussed primarily upon exercise-related changes in adiponectin. A group of 18 overweight or obese men aged 35-50 yr were divided between an experimental group who undertook two miles of walking in 30 min 4 times per week and a control group. After 12 weeks, bio-impedance measurements showed a 1.9% decrease in body fat percentage in the experimental group, although readings for the control group remained unchanged. The experimental group also showed an increase of adiponectin mRNA.

Nicklas et al. (2015) compared the response to moderate Cybex-based resistance weight-stack exercise (3 d/wk) alone with the effects of the same resistance exercise plus dieting in 126 adults aged 65-79 yr. After 5 months, the addition of dieting (a 2.5 MJ/day dietary reduction) increased the fat loss from 0.6 kg to 3.6 kg, but this was accompanied by a greater loss of lean tissue (1.1 versus 0.3 kg).

Park et al. (2003) compared the response to aerobic exercise (6 d/week) with that to a combination of aerobic exercise (3 d/wk) and resistance exercise (3 d/wk). At 24 weeks, both treatments yielded substantial decreases of body mass (-4.7 kg, -6.4 kg) relative to control subjects (+0.6 kg), and there were also substantial reductions in body fat content (-9.2% and -10.3%) versus the small decrease of -2.3% seen in control subjects.

Reichkendler et al. (2013) compared the response to two differing volumes of aerobic activity (involving energy expenditures of 2.4 versus 1.2 MJ/day) in 61 overweight men aged ~30 yr. After 11 weeks, the fat loss was slightly less with the heavier programme (3.8 kg) than with the lighter programme (4.2 kg), with a negligible 0.1 kg loss of body fat in controls. Fat was lost rather equally from subcutaneous and visceral depots in this study.

Ross et al. (2000) recruited 52 obese men aged 40-45 yr to a 12-week study. A randomized controlled trial compared dietary-induced weight loss (a 2.9 MJ/day reduction of energy intake), exercise with weight loss (a 2.9 MJ/day increase of active energy expenditure), exercise without weight loss and controls. The exercise where weight loss was allowed produced a 16% gain of aerobic fitness, and a larger decrease of total body fat (6.1 kg) than dieting (4.8 kg).

Silva et al (2010) used an autonomous exercise promotion technique in a randomized controlled trial with 239 obese women aged ~38 yr. Control subjects were given a simple educational programme. In the intervention group, a motivational initiative increased habitual physical activity by an average of 2049 steps per day, and after 12 months the experimental group had decreased their body mass by 7.3%, as compared with a decrease of only 1.7% in the control subjects.

Slentz et al. (2004) evaluated the impact of differing doses of exercise upon the body composition of 120 sedentary and overweight adults aged 40-65 yr. Treatment options included a substantial volume of vigorous exercise (32 km/wk of jogging at 65-80% of peak oxygen intake), 19 km/wk of jogging at this same intensity, and 19 km/wk of walking at 40-55% of peak oxygen intake. After 8 months, predictions of body fat based on the thickness of 4 skin-folds indicated a 4.9 kg loss of fat in the most active group, compared with 2.5 kg and 2.0 kg losses in the other 2 exercise groups, and a gain of fat mass of 0.5 kg in the control subjects. The authors underlined that 30 min of exercise per day seemed sufficient to readjust energy balance in this age group.

Vahlberg et al. (2017) looked at the ability to lose body fat one year after a stroke in 43 adults aged 65-85 yr. A half of the group undertook biweekly progressive resistance and balance exercises, and after 3 months they showed a significant loss of fat relative to controls (-1.5% versus +0.13%). However, no increase of lean tissue mass was seen in the experimental group.

Wood et al. (1983) were interested primarily in the influence of distance running on plasma levels of HDL cholesterol. They assigned 81 sedentary men aged 30-55 yr between a running programme and a control group. After one year, the runners had a substantial advantage of maximal oxygen intake (+9.0 versus -0.4 ml/[kg.min] in controls), and they also showed a large benefit in terms of changes in body fat content (-3.8% vs. +2.0%).

Yassine et al. (2000) further emphasized the fallibility of drawing conclusions about fat loss from changes in BMI. In a group of 25 obese adults aged ~66 yr, they compared the effects of exercise alone (50-60 min, 5 d/wk) with exercise plus dietary restriction (a negative energy balance of 2 MJ/day). At 12 weeks, there was a much bigger decrease of body mass when exercise was supplemented by dietary restriction, but differences in fat loss (4.2 kg versus. 6.0 kg) and waist circumference (5.6 cm versus 6 .5 cm) were not increased significantly by the introduction of dietary restriction.

In summary, 27 of 31 controlled investigations covering a wide variety of populations detailed a substantial loss of body fat attributable to the introduction of various types of exercise. Of the 4 studies with equivocal or negative findings, two involved unusual forms of exercise (trampoline and Cybex), and one showed a loss of visceral but not total fat. In general, high intensity exercise appeared to be more effective than the expenditure of an equal volume of energy at a low intensity.

**Studies on the efficacy of exercise in elderly and frail adults.**

Some 90-year-old adults can still carry out sufficient regular sessions of aerobic exercise to improve their body composition, covering distances of several kilometers per day, albeit aided by a stick or a walker. But others in this age group can only undertake seated and/or resistance exercise. Moreover, the primary objectives of programmes for the frail elderly are commonly the strengthening of muscles, the prevention of falls and/or an increase of overall mobility. Much less attention is paid to the impact of interventions upon issues such as body fat content. One systematic review (De Labra, Guimaraes-Pinheiro, Maseda, Lorenzo, and Millán-Calenti, 2015) found 8 randomized controlled studies of exercise programmes for the frail elderly, but only 2 of these specifically examined body fat content. There did not appear to be any consistent change in total body fat content, but one of the 2 reports found a lesser fat content of muscle tissue, suggesting that here had been an improvement in quality of the muscle as a result of the intervention.

Another review of exercise programmes for the frail elderly (Cadore, Rodríguez-Mañas, Sinclair, and Izquierdo, 2013) found a total of 20 relevant studies. These described enhanced balance and gait, and a reduced risk of falls as a result of increased physical activity, but none of these reports seems to have considered possible changes in body fat content. However, a careful analysis of the literature reveals at least 5 investigations where changes in body fat were examined.

Binder et al. (2005) made observations on 91 frail adults aged >78 yr. The experimental group undertook light exercise programme for 3 months, following this with 3 months of progressive resistance training. This led to an 0.8 kg increase of fat-free mass, but dual energy x-ray absorptiometry suggested that there had been no change in body fat content.

Cadore et al. (2014) conducted a randomized controlled trial on 24 adults initially aged ~91.9 yr. The intervention group undertook multi-component muscle training twice per week for 12 weeks. This resulted in gains of lean tissue and muscle strength, and computed tomography attenuation measurements suggested an improvement in the quality of skeletal muscle (since it had a lower fat content). However, no observations were made on possible changes in total body fat.

de Jong et al. (2000) recruited 161 frail adults aged ~78.6 yr to one of four options (exercise, nutritional enrichment, exercise plus nutritional change or control). The exercise sessions were held twice per week for 45 min, with a focus upon skills training, and the intensity was described as "moderate." At 17 weeks, none of the active treatments had modified BMI, waist circumference or waist-hip ratio relative to control subjects.

Villareal et al. (2006) studied 27 frail adults, all aged >65 yr. Albeit somewhat younger than many of the other studies considered in Table 14, the study found that three exercise and one behavioural session per week were effective in enhancing power, muscle

**Table 14: Effects of physical activity upon body composition, as seen in randomized controlled trials with frail elderly populations.**

| Author | Subjects | Intervention | Findings | Comments |
|---|---|---|---|---|
| Binder et al. (2006) | 91 frail adults aged >78 yr | 3 months light then 3 months progressive resistance ex. vs. light home ex. | No significant change of body fat % by DEXA | 0.8 kg increase of fat-free mass in intervention group |
| Cadore et al. (2014) | 24 adults aged ~91.9 yr; exercise and/or nutritional program | Multi-component muscle training (2 sessions/wk, 12 wk) | Increased lean tissue, reduced muscle fat infiltration | CT attenuation a measure of muscle quality |
| de Jong et al. (2000) | 143 frail adults aged ~78.6 yr | Exercise and/or nutritional enrichment vs. control | At 17 weeks, no significant change of BMI, waist circumference or waist-hip ratio relative to controls | Exercise conserved lean tissue |
| Karelis et al. (2015) | 99 frail elderly aged 65-88 yr | Resistance exercise + cysteine rich whey protein vs. casein controls | At 135 d, whey-treated group trended to decrease of body fat (0.5 kg) | 0.4 kg increase of lean body mass in exp. group |
| Tieland et al. (2012) | 62 frail elderly aged ~78 yr | Resistance exercise with or without protein supplement | At 24 wks, no change in body fat with exercise alone, but increased body fat if given protein supplement | 1.3 kg of lean mass, gains of strength & physical performance |
| Villareal et al. (2006) | 27 frail obese adults aged >65 yr | 3 ex. sessions, one behavioural session/wk | At 6 months, exp. group showed fat mass -6.6 kg, vs. +1.7 kg in controls | Aerobic power, strength & function also improved in exp. group |

strength and functional ability in the intervention group.

The exercise component of the treatment comprised 30 min of endurance exercise and 30 min of strength training. However, dietary counseling was also an important element in this programme, with the experimental subjects reducing their food intake by 3 MJ/d/week. By 6 months, the experimental group had developed a substantial advantage of body composition relative to the control subjects, with a loss of body fat (6.6 kg) rather than the increase of 1.7 kg seen in the controls. Enhanced aerobic performance seen at 6 months is probably attributable largely to the 8.4% decrease in total body mass. A second report by the same research group (Frimel, Sinacore, and Villareal, 2008) compared the effects of dieting alone with that of dieting plus exercise. The decrease of fat mass (6.8 kg) was identical for the 2 treatments, but the addition of an exercise component reduced the loss of lean tissue from 3.5 to 1.8 kg.

Several authors have carried out trials where dietary supplements were administered along with exercise programmes. Karelis et al. (2015) evaluated the benefits of a cysteine-rich whey protein, using casein as a control dietary supplement, in a trial with 99 frail elderly individuals aged 65-88 yr. After 135 d, the subjects who had received the whey supplement showed an 0.4 kg increase of lean tissue mass, and an 0.5 kg decrease of body fat content relative to comparison groups.

Tieland et al. (2012) arranged a two-armed trial, with 62 frail elderly subjects aged ~78 yr. Participants were allocated between resistance exercise, resistance exercise plus a protein supplement and a placebo control group. At 24 weeks, there was no change in body fat content with resistance exercise alone, but when a protein supplement was also provided, the body fat content was increased. The exercise programme also induced a 1.3 kg increase of lean mass, with associated gains in muscular strength and physical performance.

In summary, those developing exercise programmes for the frail elderly have to date had greater interest in enhancing muscle strength than in reducing obesity. Substantial fat loss has been achieved by a combination of exercise and dieting in this age group, but there is as yet insufficient information to determine the potential impact of an i8ncrease of habitual physical activity alone.

## Discussion and conclusions

In cross-sectional studies, investigators have typically reported that physically active individuals have substantial advantageous characteristics of body composition relative to those who are inactive (Shephard, 2019b), but such comparisons have been confounded by issues of self-selection and resulting co-variance effects such as an overall healthy lifestyle in those who are physically active. Cross-sectional evidence of the apparent efficacy of exercise is strengthened by the prospective data considered in this review, with a spontaneous or prescribed increase of habitual physical activity limiting fat accumulation with aging. Further, a growing number of randomized controlled trials have demonstrated that a deliberate increase of habitual physical activity reduces body fat content in the intervention group relative to controls.

Nevertheless, in many longitudinal interventions the beneficial changes of body composition observed in those assigned to a regimen of increased physical activity have been smaller than might have been anticipated from cross-sectional research; indeed, sometimes the differences in final body composition between experimental and control groups have had neither statistical nor clinical significance. One probable reason why longitudinal investigations tend to show smaller benefits than cross-sectional comparisons is the practical problem of maintaining a substantial increase of physical activity in the intervention group. It is notoriously difficult to maintain a significant increase of physical activity in half of a randomly selected group of individuals. Too often, little increase in the daily volume of exercise has been achieved, and investigators have had to justify their research funding by reference to the mirage of creating "greater future intentions" to increase physical activity in the intervention group. Conclusions about the efficacy of exercise programmes must be based on studies where a substantial increase of physical activity has actually been achieved.

Another problem in any longitudinal study is that all of the subjects who are recruited (both intervention and control groups) commonly have an above-average interest in health, and they may all be following an active lifestyle with a good diet before the experiment begins. There are also issues of practicality. Even if an investigation provides clear proof that an increase of physical activity has beneficial effects upon body composition in a specific test group, it may be very difficult to persuade the general population to adopt the proposed regimen. Greater research effort needs to be directed to changing social attitudes, so that an active lifestyle becomes the accepted norm of personal behaviour

Despite these various practical difficulties, the majority of longitudinal studies have demonstrated a favourable influence of greater physical activity upon body composition over a wide range of ages. In infants, a lesser accumulation of fat is seen in individuals with a high level of spontaneous physical activity, although there remains a need to examine how far it is possible for mothers and/or nursery staff to stimulate those babies that are less active to engage in a greater volume of daily physical activity, and whether such an intervention will also yield a more favourable development of their body composition.

In preschool children, there is again a need for further research on simple methods of increasing habitual physical activity. In a number of the published reports, formal interventions have had little impact upon either the child's typical level of physical activity or their body composition. However, valid conclusions about the value of greater physical activity in this age group cannot be drawn until there have been a substantial number of studies of populations where this has actually been achieved.

Summer obesity camps have usually led to a substantial immediate decrease in the body mass and body fat content of participating obese adolescents, but it has generally remained unclear how far this change should be attributed to dietary restriction rather than increased exercise. Moreover, in many instances benefits have been reversed quite quickly once the child has returned to a home environment where over-eating and a sedentary lifestyle are the norm. Finally, most camp attendees have initially been obese, and there remains a need to examine the effectiveness of such camps in developing a healthy lifestyle among children who initially are sedentary but not overweight.

In other studies of older children and adolescents, the interpretation of data has often been limited by difficulties in increasing the physical activity of experimental students relative to controls, and by weak measures of body composition (use of the BMI rather than skin-fold thicknesses or determinations of body fat content). Other issues reducing the likelihood of clear results have included inclusion of only a small number of obese individuals in the test sample, out-of-school compensation for any added physical activity during class-time, and failure to avoid increases of food intake that compensate for any increase of daily energy expenditure. Five of 8 reports based on subjective determinations of habitual physical activity have found no associations between exercise behaviour and subsequent weight gain, but in contrast 8 of 10 investigations where habitual physical activity was measured objectively, using devices such as an accelerometer, have demonstrated a positive effect of increased physical activity upon the subsequent accumulation of body fat. This striking difference presumably reflects the limited accuracy of subjective assessments of physical activity. Of 26 longitudinal studies of children and youth with group assignment, 15 again showed an advantage of body composition in those students assigned to a group where greater physical activity was encouraged. However, in 9 of the 15 trials with positive results, encouragement to greater exercise was supplemented by nutritional advice, leaving the cause of any changes in body composition unclear.

A number of early studies in adults were based upon occupational comparisons, and had as their primary concern an assessment of the influence of vigorous physical activity at work upon cardiac risk. Five of 7 occupational studies with data on body composition showed a lesser accumulation of body fat for those engaged in "heavy" employment; however, it must be kept in mind that the choice of employment is far from random, and heavy workers are characterized not only by a high level of daily energy expenditure, but also by socio-economic differences relative to sedentary workers. In leisure studies of young adults, greater physical activity has usually had a beneficial effect upon body composition. In 14 of 17 longitudinal studies (although one in women but not in men), body fat decreased, or increased at a slower rate in active individuals than in those who were more sedentary. Moreover, in middle aged and older adults, a physically active lifestyle generally seems to reduce or prevent the usual age-related weight gain experienced by sedentary individuals. Active middle-aged and older individuals had an unqualified advantage of body composition over sedentary people in 19 of 21 studies. The greater level of physical activity probably made a major causal contribution to these observed benefits, but there may also have been effects from a greater overall health consciousness among individuals who chose to remain active, relative to those who preferred a sedentary lifestyle; the contribution of this more general influence remains to be clearly evaluated.

The tendency of a person to sedentary behaviour has usually been assessed by recording he hours per week spent watching television and/or other electronic devices. Four of 6 such reports in children, and 10 of 13 studies in adults have shown an association between screen-watching indices of sedentarity and the development of obesity. Nevertheless, there remains a need to clarify the impact upon this association of a relationship between screen watching and a low overall level of physical activity, as well as the effects of snacking while watching the television. Investigators must still clarify the direction of associations between body composition and a sedentary lifestyle. It may be that a substantial body fat content predisposes to sedentary living rather than the converse. Moreover, sedentary behaviour may not be an independent parameter; measurement of the time allocated to sedentary pursuits may simply be identifying those people who choose to take little physical activity. Certainly, the association between sedentary pursuits and body fat content is weakened if data are co-varied for habitual physical activity.

Data accumulated during the acculturation of once vigorously active hunter-gatherer communities to a modern sedentary lifestyle offer yet further proof of an association between a decrease in habitual physical activity and the accumulation of body fat. Nevertheless, interpretation of such studies must remain cautious, since a part of the responsibility for the substantial changes in body composition that occur during acculturation may reflect a transition from "country" to shop food, and other consequences of adopting a western lifestyle.

In theory, the best evidence concerning the efficacy of physical activity as a means of countering obesity should come from randomized controlled trials, but in practice a number of problems remain to cloud the interpretation of such data. In children an important issue has been that more than a half of published studies have failed to induce or to sustain an adequate increase of physical activity to anticipate any beneficial response. However, focusing upon reports where a significant increase of physical activity was demonstrated, 13 of 15 investigations of children and youth found beneficial changes of body composition in response to the intervention. The largest effects were seen with programmes that were sustained for a year or more. Other characteristics of effective programming were provision of guidance on ways to improve physical activity and nutrition, a behavioural component to the intervention, modification of various aspects of the child's environment to favour physical activity, and involvement of the parents, coupled with specific efforts to increase physical activity and improve diet. In many successful initiatives, greater physical activity was combined with dietary modification, and the unique role of physical activity thus remained unclear. Certainly, the best results were obtained from a combination of increased physical activity, healthy eating and an improvement of the child's self-image (Waters et al., 2011).

In adults, randomized controlled trials have typically followed subjects for periods of 12-16 weeks, and often sample sizes have been quite small. There remains a need for large, long-term studies of the efficacy of exercise programmes in situations where no dietary constraints have been imposed. Nevertheless, the available information is fairly conclusive; 27 of 31 controlled investigations covering a wide variety of populations have shown a substantial loss of body fat attributable to both aerobic and resistance exercise. Moreover, the volumes of exercise associated with such benefits have seemed within the capacity of the average middle-aged or older adult, and have carried the additional side-benefit not seen with dieting- a conservation and even an increase of lean tissue mass.

In the frail elderly, some individuals have had difficulty in increasing their energy expenditures, except through programmes of seated or resistance exercise. Those developing exercise programmes for this age group have in general had greater interest in enhancing muscle strength than in reducing obesity. Studies have shown that substantial fat loss can be achieved in the frail elderly though a combination of exercise and dieting, but there is as yet insufficient information to determine the potential impact of an increase of habitual physical activity alone. Conservation of lean tissue mass is an important issue in this age group, and fat loss merits attention not only because of overall improvements in metabolic health, but also because the decrease in body mass increases functional capacity in the face of weakened muscles.

In summary, most pieces of longitudinal evidence thus point to the efficacy of regular physical activity in preventing and/or correcting obesity. Body fat content is reduced in those who perform an adequate volume of exercise, and this is achieved without the loss of lean tissue that is a major criticism of dietary restriction. However, there remains a need for more research on the practicalities of this approach. How well do people adhere to the various possible types of exercise intervention, relative to severe dieting? How well is fat loss maintained? And is the required volume of exercise, probably 150-250 min of moderate to vigorous aerobic activity per week, something that is acceptable to those members of the general public who are tending to become obese?

## Acknowledgments

The author acknowledges no funding relationships or other conflicts of interest.

## Author's qualifications

The author's qualifications are as follows: Roy J. Shephard, C.M., Ph.D., M.B.B.S., M.D. [Lond.], D.P.E., LL.D., D.Sc., FACSM, FCSEP, FFIMS, FAAPE.

## References

Annesi, J.J., Smith, A.E., and Tennant, G.A. (2013). Effects of a cognitive-behaviorally based physical activity treatment for 4 and 5-year-old children attending US preschools. *Int J Behav Med. 20(4)*, 562-566. https://doi.org/10.1007/s12529-013-9361-7

Ara, I., Vicente-Rodriguez, G., Perez-Gomez, J., Jimenez-Ramirez, J., Serrano-Sanchez, J.A., Dorado, C., and Calbet, J.A.L. (2006). Influence of extracurricular sport activities on body composition and physical fitness in boys: a 3-year longitudinal study. *Int J Obes. 30,* 1062-1071. https://doi.org/10.1038/sj.ijo.0803303

Avila, J.J., Gutierres, J.A., Sheehy, M.E. , Lofgren, I.E., and Delmonico, M.J. (2010). Effect of moderate intensity resistance training during weight loss on body composition and physical performance in overweight older adults. *Eur J Appl Physiol. 109(3),* 517-525. https://doi.org/10.1007/s00421-010-1387-9

Bäcklund, C., Sundelin, G., and Larsson, C. (2011). Effects of a 2-year lifestyle intervention on physical activity in overweight and obese children. *Adv Physiotherap. 13(3)*, 97-109. https://doi.org/10.3109/14038196.2011.562540

Ball, K., Brown, E.W., and Crawford, D. (2002). Who does not gain weight? Prevalence and predictors of weight maintenance in young women. *Int J. Obes Relat Metab Disord. 26*, 1570-1578. https://doi.org/10.1038/sj.ijo.0802150

Bar Or, O., and Baranowski, T. (1994). Physical activity, adiposity and obesity among adolescents. *Ped Exerc Sci. 6(4),* 348-360. https://doi.org/10.1123/pes.6.4.348

Bar-Or, O., Foreyt, J., Bouchard, C., Brownell, K., Dietz, W.H., Ravussin, E., et al. (1998). Physical activity, genetic and nutritional considerations in childhood weight management. *Med Sci Sports Exerc. 30(1)*, 2-10. https://doi.org/10.1097/00005768-199801000-00002

Baranowski, T. , Baranowski, J.C., Cullen, K.W., Thompson, D.I., Nicklas, T., Zakeri, I.F., and Rochon, J. (2003). The Fun, Food, andFitness Project (FFFP): the Baylor GEMS pilot study. *Ethn Dis. 13(1 Suppl. 1),* S30-S39.

Barefoot, J.C., Heitmann, B.L., Helms, M.J., Williams, R.G., Surwit, R.S., and Siegler, I.C. (1998). Symptoms of depression and changes in body weight from adolescnce to mid-life. *Int J Obes Metab Disord. 22,* 89-9 https://doi.org/10.1038/sj.ijo.0800647

Bell, A.C., Ge, K., and Popkin, B.M. (2002). The road to obesity or the path to prevention: motorized transportation and obesity in China. *Obes Res. 10(4),* 277-283. https://doi.org/10.1038/oby.2002.38

Bell, A.C., Ge, K., and Popkin, B.M. (2001). Weight gain and its predictors in Chinese adults. *Int J Obes Relat Metab Disord. 25*,1079-1086. https://doi.org/10.1038/sj.ijo.0801651

Berk, D.R., Hubert, H.B., and Fries, J.F. (2006). Association of changes in exercise level with subsequent disability among seniors: a 16-year longitudinal study. *J Gerontol. 61A(1),* 97-102. https://doi.org/10.1093/gerona/61.1.97

Berkey, C.S., Rockett, H.R., Field, A.E., Gillman, M.W., Frazier, A.L., Camargo, C.A., and Colditz, G.A. (2000). Activity, dietary intake and weight changes in a longitudinal study of preadolescent and adolescent boys and girls. *Pediatrics. 105(4), E56.* https://doi.org/10.1542/peds.105.4.e56

Binder, E.F., Yarasheski, K.E., Steger-May, K., Sinacore, D.R. Brown, M., Schectman, K.B , and Holloszy, J.O. (2005). Effects of progressive resistance training on body composition in frail older adults: Results of a randomized controlled trial. *J Gerontol Med. Sci. 60A(11),* 1425-1432. https://doi.org/10.1093/gerona/60.11.1425

Bocca, G., Corperleijn, E., van den Heuvel, E., Stolk, R.P., and Sauer, P.J.J. (2014). Three-year follow- up of 3-year-old to five-year-old children after participation in a multidisciplinary or a usual care obesity treatment program. *Clin Nutr. 13(6),* 1095-1100. https://doi.org/10.1016/j.clnu.2013.12.002

Bogaert, N., Steinbeck, K.S., Baur, L.A., Brock, K., and Bermingham, M.A. (2003). Food, activity and family- environmental vs. biochemical predictors of weight gain in children. *Eur J Clin Nutr. 57,* 1242-1249.https://doi.org/10.1038/sj.ejcn.1601677

Bonvin, A., Barral, J., Kakebeeke, T.H., Kriemler, S., Longchamp, A. , Schindler, C., Vidal, P.M., and Puder, J.J. (2013). Effect of a government led physical activity program on motor skills in young children attending child care centers; a cluster-randomized controlled trial. *Int J Behav Nutr Phys Activity 10:90*. https://doi.org/10.1186/1479-5868-10-90

Braet, C., Van Winkel, M., and Van Leeuwen, K. (1997). Follow-up results of different treatment programs for obese children. *Acta Pediatr. 86(4),* 397-402. https://doi.org/10.1111/j.1651-2227.1997.tb09030.x

Brownell, K.D., and Kaye, F.S. (1982). A school-based behavior modification, nutrition education, and physical activity program for obese children. *Am J Clin Nutr. 35(2),* 277-283. https://doi.org/10.1093/ajcn/35.2.277

Burke, V. , Giangiulio, N., Gillam, H.F., Beilin, L.J., and Houghton, S. (2003). Physical activity and nutrition programs for couples: a randomizd controlled trial. *J Clin Epidemiol. 56(5),* 421-432. https://doi.org/10.1016/S0895-4356(02)00610-8

Butte, N.F., Puyau., M.R., Wilson,T.A., Liu, Y., Wong, W.W., Adolp, A.L., and Zakeri, I.F. (2016). Role of physical activity and sleep duration in growth and body compositiion of preschool-aged children. *Obesity (Silver Spring). 24(6),*1328-1335. https://doi.org/10.1002/oby.21489

Butte, N.F., Puyau, M.R., Adolph, A.L., Vohra, F.A., and Zakeri, I.F. (2007). Physical activity in nonoverweight and overweight Hispoanic children and adolescents. *Med Sci Sports Exerc. 39(8)*, 1257-1266.

https://doi.org/10.1249/mss.0b013e3180621fb6

Byrd-Williams, C.E., Shaibi, G.Q., Sun, P., Lane, C.J., Ventura, E.E., Davis, J.M., Kelly, L.A., and Goran, M.I. (2008). Cardiorespiratory fitness predicts changes in adiposity in overweight Hispanic boys. *Obesity. 16(5)*, 1072-1077. https://doi.org/10.1038/oby.2008.16

Byrd-Williams, C.E., Belcher, B.R. , Spruijt-Metz, D., Davies, J.N., Ventura, E.E., Kelly, L., et al. (2010). Increased physical activity and reduced adiposity in overweight Hispanic adolescents. *Med Sci Sports Exerc. 42(3),* 478-484. https://doi.org/10.1249/MSS.0b013e3181b9c45b

Caballero, B., Clay, T., Davis, S.M., Ethelbah, B., Rock, B.H., Lohman, R., et al. (2003). Pathways: a school-based randomized controlled trial for the prevention of obesity in American Indian schoolchildren. *Am J Clin Nutr. 78(5),* 1030-1038. https://doi.org/10.1093/ajcn/78.5.1030

Cadore, L.A., Rodríguez-Mañas, L., Sinclair, A., and Izquierdo, M. (2013). Effects of different exercise interventions on risk of falls, gait ability, and balance in physically frail older adults: A systematic review. *Rejuven Res. 16(2),* 105-114. https://doi.org/10.1089/rej.2012.1397

Cadore, L.A., Casas-Herrero, A., Zambom-Ferraresi, F., Idoate, F., Millor, N., Gómez-Leocadio, M.. et al. (2014). Multicomponent exercises including muscle power training enhance muscle mass, power output, and functional outcomes in institutionalized frail nonagenarians. *Age Ageing. 36(2),* 773-785. https://doi.org/10.1007/s11357-013-9586-z

Carrell, A.L., Clark, R., Peterson, S.E., Nemeth, B.A., Sullivan, J., and Allen, D.B. (2005). Improvement of fitness, body composition, and insulin sensitivity in overweightchildren in a school-based exercise program. *Arch Pediatr Adolesc Med. 159(10),* 963-968. https://doi.org/10.1001/archpedi.159.10.963

Carson, V., Lee, E-Y., Hewitt, L., Jennings, C., Hunter, S., Kuzik, N., et al. (2017). Systematic review of relationships between physical activity and health indicators in the early years (0-4 years). *BMC Publ Health. 17(55): 854.* https://doi.org/10.1186/s12889-017-4860-0

Ching, P. L.,Willett, W,C., Rimm, E.B., Colditz, G.A., Gortmaker, S.L., and Stampfer, M.J. (1996). Activity level and risk of overweight in male health professionals. *Am J Publ Health. 86(1),* 25-30. https://doi.org/10.2105/AJPH.86.1.25

Cho, J-K. , Lee, S-H., Lee, J-Y., and Kang, H-S. (2011). Randomized controlled trial of training intensity in adiposity. *Int J Sports Med. 32(6),* 468- 475.https://doi.org/10.1055/s-0031-1271789

Chomentowski, P., Dubé, J.J., Amati, F., Stefanovic-Racic, M., Zhu, S., Toledo, F.G.S., and Goodpaster, B.H. (2009). Moderate exercise attenuates the loss of skeletal muscle mass that occurs with intentional caloric restriction-induced weight loss in older,overweight to obese adults. *J Gerontol Med Sci. 64A(5),* 575-580. https://doi.org/10.1093/gerona/glp007

Christensen, R., Overgaard, K., Carneiro, I.G. , Holtermann, A., and Søgaard, K.S. (2012). Weight loss among female health care workers-a 1-year workkplace based randomized controlled trial in the FINALE health study. *BMC Publ Health. 12:625.* https://doi.org/10.1186/1471-2458-12-625

Christiakis, C.S., Sajecki, S., Huillman, R.W., Miller, E., Blumenthal, S., and Archer, M. (1996). Effect of a combined nutrition education and physical fitness program on the weight status of obese high school boys. *FASEB J, 25(1)*, 15-19. PMID:5006567

Church, T.S., Earnest, C.P., Skinner, J.S., and Blair, S.N. (2007). Effects of different doses of physical activity on cardiorespoiratory fitness among sedentary overweight or obese postmenopausal women with elevated blood pressure. A https://doi.org/10.1001/jama.297.19.2081

Clark, J.E. (2015). Diet, exericse, or diet with exercise; comparing the effectivenss of treatment options for weight loss and changes of fitness for adults (18-65 years old) who are overfat; systematic review and meta-analysis. *J Diabetes Metab Disord. 14: 31.* https://doi.org/10.1186/s40200-015-0204-8

Coakley, E.H., Rimm, E.B., Colditz, G., Kawachi, I., and Willett, W. (1998). Predictors of weight change in men: Results from the health professionals follow-up study. *Int J Obes. 22(2)*, 89-96. https://doi.org/10.1038/sj.ijo.0800549

Coker, R.H., Williams, R.H., Kortebein, P.M., Siullivan, D.H., and Evans, W.J. (2009). Influence of exercise intensity on abdominal fat and adiponectin in elderly adults. *Met Syndr. 7(4),* 363-368. https://doi.org/10.1089/met.2008.0060

Coleman, K.J., Tiller, C.L., Sanchez, J., Heath, E.M., Sy, O., Milliken, G., and Dzewaltowski, D.A. (2005). Prevention of the epidemic increase in child risk of overweight in low income schools. The El Paso cordinated approach to child health. *Arch Pediatr Adolesc Med. 159(3),* 217-224. https://doi.org/10.1001/archpedi.159.3.217

Collipp, P.J. (1975). An obesity program in public schools. *Pediatr Ann. 4(5)*, 58-76. https://doi.org/10.3928/0090-4481-19750501-07

Crawford, D.A., Jeffery, R.W., and French, S.A. (1999). Television viewing, physical inactivity and obesity. *Int J Obes Metab Relat Disord. 23(4),* 437-440. https://doi.org/10.1038/sj.ijo.0800845

Cuff, D.J., Meneilly, D.S., Martin, A., Ignaszewski, A., Tildesley, H.D., and Frohlich, J.J. (2093). Effective exercise modality to reduce insulin resistance in women with type 2 diabetes. *Diabetes Care. 26(11),* 2977-2982. https://doi.org/10.2337/diacare.26.11.2977

Danielson, A., Thorsson, O., Karlsson, M.K., Wollmer, P., Andersen, L.B., and Dencker, M. (2018). School-based study found that physical activity and aerobic fitness predicted increases in local body fat and abdominal fat at a mean age of 9.8 years. *Acta Pediatr. 107(10),* 1810-1817. https://doi.org/10.1111/apa.14289

Davies, P.S., Day, J.M., and Lucas, A. (1991). Energy expenditure in early infancy and later body fatness. *Int J Obes. 15(11)*, 727-731. PMID 1778657

Davison, K.K., and Birch, L.L. (2011). Child and parent characteristics as predictors of change in girls' body mass index. *Int J Obes. 25(12),* 1834-1842. https://doi.org/10.1038/sj.ijo.0801835

De Coen, V., De Bourdeaudhuij, I., Verbestel, V., Maes, L., and Vereecken, C. (2013). Risk factors for childhood overweight: a 30 month longitudinal study of 3- to 6-year-old children. *Publ Health Nutr. 17(9),* 1993-2000. https://doi.org/10.1017/S1368980013002346

de Jong, N., Chin A Paw, M.G.M., de Groot, L.C.P.G.M., Hiddink, G.J., and van Staveren, W.A. (2000). Dietary supplements and physical exercise affecting bone and body composition in frail elderly persons. *Am J Publ Health. 90(6)*, 947-954. https://doi.org/10.2105/AJPH.90.6.947

De Labra, C., Guimaraes-Pinheiro, C., Maseda, A., Lorenzo, R., and Millán-Calenti, J.C. (2015). Effects of physical exercise interventions in frail older adults: a systematic review of randomized controlled trials. *BMC Geriatrics. 15:154* https://doi.org/10.1186/s12877-015-0155-4

de Vries, A.G.M., Huiting, H.G., van den Heuvel, E.R., L'Abbé, G., Corpeieijn, E.C., and Stolk, R.P. (2015). An activity stimulation programme during a child's first year reduces some indicators of obesity at the age of two-and-a-half. *Acta Pediatr. 104(4)*, 414-421. https://doi.org/10.1111/apa.12880

Dennison, B.A., Russo, T.J., Burdick, P.A., and Jenkins, P.L. (2004). An intervention to reduce television viewing by preschool children. *Arch Pediatr Adolesc Med. 158(2),* 170-176. https://doi.org/10.1001/archpedi.158.2.170

Després, J-P., Bouchard, C., Savard, R., Tremblay, A., Marcotte, M., and Thériault, G. (1984). Effect of exerciee training and detraining on fat cell lipolysis in men and women. *Eur J Appl Physiol. 53(1),* 25-30. https://doi.org/10.1007/BF00964685

Di Pietro, L., Kohl, H.W., Barlow, C.E., and Blair, S.N. (1998). Improvements in cardiorespiratory fitness attenuate age-related weight gain in healthy men and women: the Aerobics Centre longitudinal study. *Int J Obes Relat Metab Disord. 22(1)*, 55-62. https://doi.org/10.1038/sj.ijo.0800543

Di Pietro, L., Seeman, T.E., Stachenfeld, N.S., Katz, L.D., and Nadel, E.R. (1998). Moderate intensity aerobic training improves glucose tolerance independent of abdominal adiposity. *J Am Geriatr Soc. 46(7),* 875-879.

https://doi.org/10.1111/j.1532-5415.1998.tb02722.x

Di Pietro, L., Dziura, J., and Blair, S.N., (2004). Estimated change in physical activity level (pal) and prediction of 5-year weight chnages in men; The Aerobics Center longitudinal study. *Int J Obes Relat Metab Disord. 28,* 1541-1547. https://doi.org/10.1038/sj.ijo.0802821

Donges, C.E., Duffield, R., Guelfi, K.J., Smith, G.C., Adams, D.R., and Edge, J.A. (2013). Comparative effects of single-mode vs. duration matched concurrent exercise training on body composition, low-grade inflammation, and glucose regulation in sedentary, overweight and middle-aged men. *Appl Physiol Nutr Metab. 38(7),* 779-788. https://doi.org/10.1139/apnm-2012-0443

Donnelly, J.E., Greene, J.L., Gibson, C.A., Smith, B.K., Washburn, R.A., Sullivan, D.K., et al. (2009). Physical activity across the curriculum (PAAC): a randomized controlled trial to promote physical activity and diminish overweight and obesity in elementary school children. *Prev Med. 49(4)*, 336-341. https://doi.org/10.1016/j.ypmed.2009.07.022

Donnelly, J.E., Honas, J.J., Smith, B.K., Mayo, M.S., Gibson, C.A., Sullivan, D.K. et al. (2013). Aerobic exercise alone results in clinically significant weight loss for men and women: Midwest exercise trial 2. *Obesity. 21(3),* E219-E228. https://doi.org/10.1002/oby.20145

Ekelund, U., Brage, S., Franks, P.W., Hennings, S., Emms, S., Womg, M-W., and Wareham, M.J. (2005). Physical activity energy expenditure predicts changes in body composition in middle-aged healthy whites: effect modification by age. *Am J Clin Nutr. 81(5)*, 964-969. https://doi.org/10.1093/ajcn/81.5.964

Ekelund, U., Sardinha, L.B., Andersen, S.A., Harro, M., Franks, P.W., Brage, S., et al. (2004 ). Associations between objectively assessed physical activity and indicators of body fatness in 9- to 10-year old European children: a population-based study from 4 distinct regions in Europe (the European Youth Heart Study). *Am J Clin Nutr, 80(3),* 584-590. https://doi.org/10.1093/ajcn/80.3.584

Ekelund, U., Brage, S., Besson, H., Sharp, S., and Wareham, N.J. (2008). . Time spent being sedentary and weight gain in healthy adults: reverse or bidirectional causality? *Am J Clin Nutr. 88(3)*, 612-617. https://doi.org/10.1093/ajcn/88.3.612

Finkelstein, E.A., Tan, Y-T., Malhotra, R., Lee, C-F., Goh, S-S., and Saw, S-M. (2013). A cluster randomized controlled trial of an incentive-based outdoor physical activity program. *J Pediatr. 163(1),* 167-172. https://doi.org/10.1016/j.jpeds.2013.01.009

Fitzgibbon, M.L., Stolley, M.R., Schiffer, L.A., Braunschweig, C.L., Gomez, S.L., van Horn, L., and Dyer, A.R. (2011). Hip-hop to health Jr. Obesity prevention effectiveness trial: Postintervention results. *Pediatr Obes. 19(5),* 994-1003. https://doi.org/10.1038/oby.2010.314

Fogelholm, M., Kujala, U., Kaprio, J, and Sarna, S. (2000). Predictors of weight change in middle-aged and old men. *Obes Res. 8(5)*, 367-373. https://doi.org/10.1038/oby.2000.44

Fogelholm, M., and Kukkonen-Harjula, K. (2000). Does physical activity prevent weight gain- a systematic review. *Obes Rev. 1(2)*, 95-111. https://doi.org/10.1046/j.1467-789x.2000.00016.x

Foster, G.D., Wadden, T.A.,and Brownell, K.D. (1985). Peer-led program for treatment and prevention of obesity in the schools. *J Consult Clin Psychol. 53(4)*, 538-540. https://doi.org/10.1037/0022-006X.53.4.538

Francis, L.A., Lee, Y., and Birch, L.L. (2003). Parental weight status and girls' television viewing, snacking and body mass indexes. *Obes Res. 11(1),* 148-151. https://doi.org/10.1038/oby.2003.23

Franz, M.J., VanWormer, J.J., Crain, A.L., Boucher, J.L., Histon, T., Caplan, W., Bowman, J.D., and Pronk, N.P. (2007). Weight loss outcomes: a systematic review and meta-analysis of weight loss clinical trials with a minimum 1-year follow-up. *J Am Diet Assoc. 107(10),* 1755-1767. https://doi.org/10.1016/j.jada.2007.07.017

French, S.A., Jeffery, R.W., and Murray, D. (1999). Is dieting good for you? Prevalence, duration and associated weight and behavioral changes for specific weight loss strategies over four years in US adults. *Int J Obes Relat*

*Metab Disord. 23,* 320- 327. https://doi.org/10.1038/sj.ijo.0800822

Friedenreich, C.M., Neilson, H.K., O'Reilly, R., Duha, A., Yasui, Y., Morielli, A.R., Adams, S.C. and.Courneya, K.S. (2015). Effects of a high vs. moderate volume of aerobic exercise on adiposity outcomes in posymenopausal women: A randomized clinical trial. *JAMA Oncol. 1(6),* 766-776. https://doi.org/10.1001/jamaoncol.2015.2239

Friedenreich, C.M., Woolcott, C.G., McTiernan, A., Terry, T., Brant, R., Ballard-Barbash, R. et al. (2011). Adiposity changes after a 1-year aerobic exercise intervention among postmenopausal women: a randomized controlled trial. *Int J Obes. 35,* 427-435. https://doi.org/10.1038/ijo.2010.147

Frimel, T.N., Sinacore, D.R., and Villareal, D.T (2008). Exercise attenuates the weight-loss-induced reduction in muscle mass in frail obese older adults. *Med Sci Sports Exerc. 40(7),* 1213-1219. https://doi.org/10.1249/MSS.0b013e31816a85ce

Gately, P.J., Cooke, C.B., Butterly, R.J., Mackreth, P., and Carroll, S. (2000a). The effects of a children's summer camp programme on weight loss, with a 10-month follow-up. *Int J Obes. 24*, 1445-1453. https://doi.org/10.1038/sj.ijo.0801405

Gately, P.J., Cooke, C.B., Butterly, R.J., Knight, C., and Carroll, S. (2000b). The acute effects of an 8-week diet, exercise and educational camp program for obese children. *Ped Exerc Sci. 12(4),* 413-423. https://doi.org/10.1123/pes.12.4.413

Gentile, D.A., Welk, G., Eisenmann, J.C., Reimer, R.A., Walsh, D.A., Russell, D.W. et al. (2009). Evolution of a multi/ple ecological level child obesity prevention program: Switch what you Do, View and Chew. *BMC Med. 7: 49*. https://doi.org/10.1186/1741-7015-7-49

Gittelson, J., and Park, S. (2018). School- and community-based interventions for childhood obesity. In: M.S. Freemark (ed.), *Pediatric Obesity , 2nd ed.*. Cham, Switzerland, Humana Press, pp. 589-612 https://doi.org/10.1007/978-3-319-68192-4_34

Glass, C.M., Haas, S.A., and Reither, E.N. (2010). The skinny on success: Body mass, gender and occupational standing across the life course. *Social Forces. 88(4),*1777-1806. https://doi.org/10.1353/sof.2010.0012

Goldfield, G.S., Mallory, R., Parker, T., Cunningham, T., Lumb, A., Parker, K., et al.. (2006). Effects of open-loop feedback on physical activity and television viewing in overweight and obese children: A randomized controlled trial. *Pediatrics. 118(1): e157* https://doi.org/10.1353/sof.2010.0012

Gorely, T., Nevill, M.E., Morris, J.G., Stensel, D.J., and Nevill, A. (2009). Effect of a school-based intervention to promote healthy lifestyles in 7-11 year old children. *Int J Behav Nutr Phys Activity 6:5*. https://doi.org/10.1186/1479-5868-6-5

Guo, S.S., Zeller, C., Chumlea, W.C., and Siervogel, W. (1999). Aging, body composition, and lifestyle: the Fels longitudinal study. *Am J Clin Nutr. 70(3)*, 405- 411. https://doi.org/10.1093/ajcn/70.3.405

Haapanen, N., Miilunpalo, S., Pasanen, M. Oja, P., and Vuori, I. (1997). Association between leisure time physical activity and 10-year body nass change among working-aged men and women. *Int J Obes. 21*, 288-296. https://doi.org/10.1038/sj.ijo.0800403

Hancox, R.J., Milne, B.J., and Poulton, R. (2004). Association between child and adolescent television viewing and adult health: a longitudinal birth cohort study. *Lancet. 364(9430)*, 257-262. https://doi.org/10.1016/S0140-6736(04)16675-0

Harris, K.C., Kuramoto, L.C , Schulzer, M.,and Retallack, J.E. (2009). Effect of school-based physical activity interventions on body mass index in children: a meta- analysis. *Can Med Assoc J. 180(7),* 719-726. https://doi.org/10.1503/cmaj.080966

Heitmann, B.L., Kaprio, J., Harris, J.R., Rissanen, A., Korkeila, M., and Koskenvuo, M. (1997). Are genetic determinants of weight gain modified by leisure time physical activity? *Am J Clin Nutr. 66(3)*, 672-678. https://doi.org/10.1093/ajcn/66.3.672

Ho, S.S., Dhalial, S.S., Hills, A.P., and Pal, S. (2012). The effect of 12 weeks of aerobic, resistance or combination exercise training on cardiovascular risk factors in the overweight and obese in a randomized trial. *BMC Publ Health. 12:* 704. https://doi.org/10.1186/1471-2458-12-704

Hollis, J.L., Sutherland, R., Campbell, L., Morgan, P.J., Lubans, D.R., Nathan, N., et al. (2016). Effects of a school-based physical activity intervention on adiposity in adolescents from economically disadvantaged communities: secondary outcomes of the "Physical Activity 4 Everyone" RCT. *Int J Obes. 40,* 1486-1493. https://doi.org/10.1038/ijo.2016.107

Hopper, C.A., Munoz, K.D., Gruber.M.B., and Nguyen, K.P. (2005). The effects of a family fitness program on the physical activity and nutrition behaiors of third- grade children. *Res Quart Ex Sport. 76(2),* 130-139. https://doi.org/10.1080/02701367.2005.10599275

Hu, F.B., Li, T.Y., Colditz, G.A., Willett, W.C., and Manson, J.E. (2003). Television watching and other sedentary behaviors in relation to risk of obesity and type 2 diabetes mellitus in women. *JAMA. 289(14),* 1785-1791. https://doi.org/10.1001/jama.289.14.1785

Hughes, A., Stewart, L., Chapple, J., McColl, J.H., Donaldson, M., Kelnar, C.J.H., et al. (2008). Randomized controlled trial of a best practice individualized behavioral program for treatment of childhood overweight: Scottish childhood overweight treatment trial (SCOTT). *Pediatrics. 121: e539.* https://doi.org/10.1542/peds.2007-786

Huo, B., Mazroo, J., Banks, J., and Marshall, A. (2019). Are cities good for health? A study of the impacts of planned irbanization in China. *Int J Epidemiol , In press.*

Hurling, R., Catt, M., De Boni, M., Fairley, B.W., Hurst, T., Murray, P., Richardson, A., and Sodhi, J.S. (2007). Using internet and mobile phone technolgy to deliver an automated physical activity program: Randomized controlled trial. *J Med Internet Res, 9(2): e7.* https://doi.org/10.2196/jmir.9.2.e7

Huynh, D.T.T., Dibley, M.J., Sibbritt, D., Tran, H.T.M., and Le, Q.T.K. (2011). Influence of contextual and individual level risk factors on adiposity in a pre-school child cohort in Ho Chi Min City, Vietnam. *Int J Pediatr Obes. 6(Suppl. 3),* e487-e500. https://doi.org/10.3109/17477166.2011.575153

Irving, B.A., Davis, C.K., Brock, D.W., Weitman, J.Y., Swift, D., Barrett, E.J. et al. (2008). Effect of exercie training intensity on abdominal visceral fat and body composition. *Med Sci Sports Exerc. 40(11),* 1863-1872. https://doi.org/10.1249/MSS.0b013e3181801d40

Irwin, M.L., Yasui, Y., Ulrich, G.M., Bowen, D., Rudolph, R.E., Schwartz, R.S., Yukawa.M., et al. (2003). Effect of exercise on total and intra-abdominal body fat in postmenopausal women. A randomized controlled trial. *JAMA. 289(3),* 323-330. https://doi.org/10.1001/jama.289.3.323

Janssen, I., and LeBlanc, A.G. (2010). Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *Int J Behav Nutr Phys Activity 7:40.* https://doi.org/10.1186/1479-5868-7-40

Jefferson, M.E, Nicklas, B.J., Chmelo, E.A., Crotts, C.I, Shaltout, H.A., Diz, D.I, Marsh, A.P., and Brinkley, T.E. (2016). Effects of resistance training with and without caloric restriction on arterial stiffness in overweight and obese older adults. *Am J Hypertens. 29(4,)* 494-500. https://doi.org/10.1093/ajh/hpv139

Jetté, M., Barry, W., and Pearlman, L. (1977). The effects of extracurricular physical activity on obese adolescents. *Can J Publ Health. 68(1),* 39-42. https://www.jstor.org/stable/41987544

Johannsen, D.L. , Welk, G.J., Sharp, R.L., and Flakoll, P.J. (2008). Differences in daily energy expenditure in lean and obese women: The role of posture allocation. *Obesity (Silver Spring). 16(1),* 34-39. https://doi.org/10.1038/oby.2007.15

Johansson, E., Böckerman, P., Kiiskinen, U., and Heliövaara, M. (2009). Obesity and labour market success in Finland: The difference between having a high BMI and being fat. *Econ Hum Biol. 7(1),* 36-45. https://doi.org/10.1016/j.ehb.2009.01.008

Johansson, H. , Kanis, J.A., Odén, A, McCloskey, E., Chapurlat, R.D., Christiansen, C., et al. (2014). A meta-analysis of the association of fracture risk and body mass index in women. *J Bone Min Res. 29(1)*, 223-233. https://doi.org/10.1002/jbmr.2017

Johnson, M.S., Figuera-Colon, R., Herd, S.L., Fields, D.A., Sun, M., Hunter, G.R., and Goran, M.L. (2000). Aerobic fitness, not energy expenditure, influences subsequent increase in adiposity in black and white children. *Pediatrics. 106(4): E50.* https://doi.org/10.1542/peds.106.4.e50

Jung, J.Y., Han, K.A., Ahn, H.J., Kwon, H.R., Lee, J.H., Park, K.S., and Min, K.W. (2012). Effects of aerobic exercise intensity on abdominal and thigh adipose tissue and skeletal muscle attenuation in overweight women with type 2 diabetes mellitus. *Diabetes Metab J. 36(3)*, 211-221. https://doi.org/10.4093/dmj.2012.36.3.211

Kahn, H.S., Tatham, L.M., Rodriquez, C., Calle, E.E., Thun, M.J., and Heath, C.W. (1997). Stable behaviors associated with adults' 10-year change in body mass index and the likelihood of gain at the waist. *Am J Publ Health. 87(5)*, 747-754. https://doi.org/10.2105/AJPH.87.5.747

Kain, J., Uauy, R., Albala, Vio F., Cerda, R., Leyton, B., et al. (2004). School-based obesity prevention in Chilean primary school children: methodology and evaluation of a controlled study. *Int J Obes Relat Metab Disord. 28(4)*, 483-493. https://doi.org/10.1038/sj.ijo.0802611

Kameth, C.C., Vickers, K.S., Ehrlich, A., McGovern, L., Johnson, J., Singhal, V., et al. (2008). Clinical review: Behavioral interventions to prevent childhood obesity: A systematic review and metaanalyses of randomized trials. *J Clin Endocrinol Metab. 93(12)*, 4606-4615. https://doi.org/10.1210/jc.2006-2411

Karelis, A.D., Messier, V. , Suppère, C., Briand, P., and Rabasa-Lhoret, R. (2015). Effect of cysteine-rich whey protein (Immunocal) supplementation in combination with resistance training of muscle strength and lean body mass in non-frail elderly subjects: A randomized, double blind, controlled study *J Nutr Health Aging. 19(5)*, 531-536. https://doi.org/10.1007/s12603-015-0442-y

Karner-Rezek, K., Knechtle, B., Fenzl, M., Schlegel, C., Konrad, M., and Rosemann, T. (2013). The effects of an 8-week multi-component inpatient treatment program on body composition and anaerobic fitness in overweight and obese children and adolescents. *Int J Gen Med, 6*, 159-166. https://doi.org/10.2147/IJGM.S40187

Karstoft, K., Winding, K., Knudsen, S.H., Nielsen, J.S., Thomsen, C., Pedersenj, B.K., and Solomon, T.P.J. (2013). The effects of free-living interval-walking training on glycemic control, body composition and physical fitness in type 2 diabetic patients. A randomized controlled trial. *Diabetes Care. 36(2)*, 228-236. https://doi.org/10.2337/dc12-0658

Kawachi, I., Troisi, R.J., Rotnitsky, A.B., Coakley, E.H., and Colditz, G.A. (1996). Can physical activity minimize weight gain in women after smoking cessation? *Am J Publ Health. 86(7)*, 999-1004. https://doi.org/10.2105/AJPH.86.7.999

Kimm, S.Y., Barton, B.A., Obarzanek, E., McMahon, R.P., Abry, Z.I., Waclawiw, M.A., et al. (2001). Racial divergence in adiposity during adolescence. The NHLBI Growth and Health Study. *Pediatrics. 107*, e34. https://doi.org/10.1542/peds.107.3.e34

Kipping, R.R., Payne, C., and Lawlor, D.A. (2008). Randomised controlled trial adapting U.S. school obesity prevention to England. *Arch Dis Childh. 93,* 469-473. https://doi.org/10.1136/adc.2007.116970

Klesges, R.C., Kleges, L.M., Eck, L.H., and Shelton, M.L. (1995). A longitudinal assessment of accelerated weight gain in pre-school children. *Pediatrics. 95(1)*, 126-130. PMID: 7770289

Klesges, R C., Klesges, L.M., Haddock, C.K., and Eck, L.H. (1992). A longitudinal analysis of the impact of dietary intake and physical activity on weight change in adults. *Am J Clin Nutr. 55(4),* 818-822. https://doi.org/10.1093/ajcn/55.4.818

Klesges, R.C., Obarzanek, E., Kumanyika, S., Murray, D.M., Klesges, L.M., Relyea, G.E., et al. (2010). The Memphis girls health enrichment studies (GEMS). Anevaluation of the efficacy of a 2-year obesity prevention program in African American girls. *Arch Pediatr Adolesc Med. 164(11)*,1007-1014. https://doi.org/10.1001/archpediatrics.2010.196

Koh-Banerjee, P., Chu, N.F., Spiegelman, D., Rosner, B., Colditz, G., Willett, W., and Rimm, E. (2003). Prospective study of the association of changes in dietary intake, physical activity, alcohol consumption, and smoking with a 9-y gain in waist circumference among 16,587 US men. *Am J Clin Nutr. 78(4)*, 719-72. https://doi.org/10.1093/ajcn/78.4.7197.

Kriemler, S., Zahner, L., Schindler, C., Meyer, U., Hartmann, T., Hebestreit, H., et al. (2010). Effects of school-based physical activity programme (KISS) on aerobic fitness and adiposity in prImary schoolchildren: cluster-randomised trial. *Brit Med J. 340, c785.* https://doi.org/10.1136/bmj.c785

Kromholz, H. (2012). The impact of a 20-month physical activity intervention in child care centers on motor performance and weight in overweight and healthy weight preschool children. *Percept Mot Skills Sport. 115(3),* 919-932. https://doi.org/10.2466/06.10.25.PMS.115.6.919-932

Ku, L.C., Shapiro, L.R., Crawford, P.B. and Huenemann, R.L. (1981). Body composition and physical activity in 8-year-old children. *Am J Clin Nutr. 34(12)*, 2770-2775. https://doi.org/10.1093/ajcn/34.12.2770.

Kwon, H.R., Min, K.W., Ahn, H.J., Seok, H.G., Koo, B.K., Kim, H.C., and Han, K.A. (2010). Effects of aerobic exercise on abdominal fat, thigh muscle mass and muscle strength in type 2 diabetic subjectS. *Korean Diabetes J. 34(1),* 23-31. https://doi.org/10.4093/kdj.2010.34.1.23

Lansky, D., and Brownell, K.D. (1982). Comparison of school-based treatments for adolescent obesity. *J Sch Health. 52(8)*, 383-387. https://doi.org/10.1111/j.1746-1561.1982.tb07140.x

Lansky, D., and Vance, M.A. (1983). School-based intervention for adolescent obesity: Analysis of treatment, randomly selected control, and self-selected control subjects. *J Consult Clin Psychol. 51(1),* 147-148. https://doi.org/10.1037/0022-006X.51.1.147

Lazaar, N., Aucouturier, J., Ratel, S., Rance, M., Meyer, M., and Duché, P. (2007). Effect of physical activity intervention on body, composition in young children: influence of body mass index status and gender. *Acta Pediatr. 96(9)*, 1315-1320. https://doi.org/10.1111/j.1651-2227.2007.00426.x

Lehmann, R., Vokac, A., Niedermann, K., Agosti, K., and Spinas, G.A. (1995). Loss of abdomInal fat and improvement of the cardiovascular risk profile by regular moderate exercise training in patients with NIDDM. *Diabetologia. 38 (11)*, 1313-1319. https://doi.org/10.1007/BF00401764

Lewis, C.E., Smith, B.E., Wallace, O.D., Williams, O.D., Bild, D.E., and Jacobs, D.R. (1997). Seven year trends in body weight and associations of weight change with lifestyle and behavioral characteristics in black and white young adults: the CARDIA Study. *Am J Publ Health. 87(4),* 635-642. https://doi.org/10.2105/AJPH.87.4.635

Li, R., O'Connor, L., Buckley, D., and Specker, B. (1995). Relation of activity levels to body fat in infants 6 to 12 months of age. *J Pediatr. 126(3)*, 353-357. https://doi.org/10.1016/S0022-3476(95)70447-7

Litterell, K., Hilligoss, N., Kirschner, C., Petty, R.G., and Johnson, C.G. (2003). The effects of an educational intervention on antipsychotic-induced weight gain. *J Nurs Scholarsh, 35(3),* 237-241. https://doi.org/10.1111/j.1547-5069.2003.00237.x

Lohman, T., Thompson, J., Going, S., Himes, J.H., Caballero, B., Norman, J., Cano, S., and Ring, K. (2003). Indices of changes in adiposity in American Indian children. *Prev Med. 17(6 Part 2)*, S91-S96. https://doi.org/10.1016/j.ypmed.2003.08.004

Luepker, R.V., Perry, C.L., McKinlay, S.M., Nader, P.R., Parcel, G.S., Stone, E.J., et al. (1996). Outcomes of a field trial to improve children's dietary patterns and physical activity. The Child and Adolescent trial for cardiovacular health (CATCH). *JAMA. 275(10),* 768-776. https://doi.org/10.1001/jama.1996.03530340032026

Macdonald, H.M., New, S.A., Campbell. M.K., and Reid, D.M. (2003). Longitudinal changes in weight in perimenopausal and early postmenopausal women: effects of dietary intake, energy expenditure, dietary calcium intake and hormone replacement therapy. *Int J Obes Relat Metab Disord. 27(6),* 669-676. https://doi.org/10.1038/sj.ijo.0802283

Magnusson, K.T., Sigurgeirsson, O., Sveinsson, T., and Johansson, E. (2011). Assessment of a two school-based activity intervention among 7-to 9-year-old children. *Int J Behav Nutr Phys Activity 8: 138.*

https://doi.org/10.1186/1479-5868-8-138

Maillard, F., Pereira, B., and Boisseau, N. (2018). Effect of high-intensity interval training on total, abdominal and visceral fat mass: A meta-analysis. *Sports Med, 4(2),* 269-288. https://doi.org/10.1007/s40279-017-0807-y

Mamalakis, G., Kafatos, A., Manios, Y., Anagnostopolou, T., and Apostolaki, I. (2000). Obesity indices in a cohort of primary schoolchildren in Crete: A six-year prospective study. *Int J Obes Metab Disord. 24(6),* 765-771. https://doi.org/10.1038/sj.ijo.0801223

Marcos-Pardo, P.J., Martínez-Rdriguez, A., and Gil-Arias, A. (2018). Impact of motivational resistance-training programme on adherence and body composition in the elderly. *Nature Scientific Reports. 8:*1370. https://doi.org/10.1038/s41598-018-19764-6

Marcus, C., Nyberg, G., Nordenfelt, A., Karpmyr, M., Kowalski, J., and Ekelund, U. (2005). A 4-year cluster-randomized controlled childhood obesity prevention study: STOPP. *Int J Obes. 33*, 408-417. https://doi.org/10.1136/jech-2014-205211

Martin, A., Panter, J., Suhrcke, M., and Ogilvie, D. (2015). Impact of changes in mode of travel to work on changes in body mass index: evidence from the British Household Survey Panel. *J Epidemiol Community Health. 69(8)*, 753-761. https://doi.org/10.1136/jech-2014-205211

May, A.M., Romaguera, D., Travier, N., Ekelund, U., Bergmann, M.M., Kaaks, R., et al. (2012). Combined impact of lifestyle factors on prospective change in body weight and waist circumference in participants of the EPIC-PANACEstudy. *PLoS ONE. 7(11): e50712.* https://doi.org/10.1371/journal.pone.0050712

McCallum, Z., Wake, M., Gerner, B., Baur, L.A., Gibbons, K., Gold, L., et al. (2007). Outcome data from the LEAP (Live, eat and play) trial: A randomized controlled trial of a primary care intervention for childhood overweight/mild obesity. *Int J Obes. 31(4)*, 630-636. https://doi.org/10.1038/sj.ijo.0803509

McGovern, L., Johnson, J.N., Paulo, R , Hettinger, A., Singhal, V., Kamath, C., Erwin, P.J., and Montori, V.M. (2008). Treatment of pediatric obesity: A systematic review and meta-analysis of randomized trials. *J Clin Endocrinol Metab. 93(12),* 4600-4605. https://doi.org/10.1210/jc.2006-2409

Mcmurray, R.C., Harrell, J.S., Bangdiwala, S.I., Bradley, C.B., Deng, S., and Levine, A. (2002). A school-based intervention can reduce body fat and blood pressure in young adolescents. *J Adolesc Health. 31(2)*, 125-132. https://doi.org/10.1016/S1054-139X(02)00348-8

McTiernan, A., Sorensen, B., Irwin., M.L., Morgan, A., Yasui, Y., Rudolph, R.E., et al. (2007). Exercise effect on weight and body fat in men and women. *Obesity. 15(6)*,1496-1512.https://doi.org/10.1038/oby.2007.178

Messier, V., Rabasa-Lhoret, R., Doucet, E., Brochu, M., Lavoie, J.M., Karells, A., et al. (2010). Effect of the addition of a resistance training programme to a caloric restriction weight loss prevention on pyschosocial factors in overweight and obese post-menopausal women: A Montreal-Ottawa New Emerging Team study. *J Sports Sci. 28(1),* 83-92. https://doi.org/10.1080/02640410903390105

Metcalf, B., Henley, W., and Wilkin, T. (2012). Effectiveness of intervention on physical activity of children : systematic review and meta-analysis of controlled trials with objectively measured outcomes (Early Bird 54). *Br Med J. 345: e5888.* https://doi.org/10.1136/bmj.e5888

Metcalf, B.S., Voss, L.D., Hosking, J., Jeffery, A.N., and Wilkin, T.J. (2008). Physical activity at the government recommended level and obesity-related health outcomes: a longitudinal study (Early Bird 37). *Arch Dis Child. 93(9),* 772-777. https://doi.org/10.1136/adc.2007.135012

Miguel-Berges, M.L., Reilly, J.J., Moreno Aznar, L.A., and Jiménez-Pavón, D. (2018). Associations between pedometer-determined physical activity and adiposity in children and adolescents: Systematic review. *Int J Sports Med. 28(1),* 64-75.

https://doi.org/10.1097/JSM.0000000000000419

Miller, W.C., Koceja, D.M., and Hamilton, E.J. (1997). A meta-analysis of the past 25 years of weight loss research using diet, exercise or diet plus exercise intervention. *Int J Obes. 21(10),* 941-947. https://doi.org/10.1038/sj.ijo.0800499

Mo-suwan, L, Pongprapai, S., Junjana, C., and Puetpaiboon, A. (1998). Effects of a controlled trial of a school-based exercise program on the obesity indexes of preschool children. *Am J Clin Nutr. 68(5),* 1006-1011. https://doi.org/10.1093/ajcn/68.5.1006

Moghadasi, M., Mohebbi, H., Rahmani-Nia, F., Hassan-Nia, S., and Noroozi, H. (2013). Effects of short-term lifestyle activity modification on adiponectin mRNA expression and plasma concentratioins. *Eur J Sports Sci. 13(4),* 378-385. https://doi.org/10.1080/17461391.2011.635701

Monda, K.L., Adair, L.S., Zhai, F., and Popkin, B.M. (2008). Longitudinal relationships between occupational and domestic physical activity patterns and body weight in China. *Eur J Clin Nutr. 62(11),* 1318-1325. https://doi.org/10.1038/sj.ejcn.1602849

Monsivais, P., Martin, A., Suhrke, M., Forouhi, N.G., and Wareham, N.J. (2015). Job-loss and weight gain in British adults: evidence from two longitudinal studies. *Soc Sci Med. 143*, 223-231. https://doi.org/10.1016/j.socscimed.2015.08.052

Moore, L.L., Gao, D., Bradlee, M.L., Cupples, L.A., Sundarajan-Ramamurti, A., Proctor, M.H., et al. (2003). Does early physical activity predict body fat change throughout childhood? *Prev Med. 37(1)*, 10-17. https://doi.org/10.1016/S0091-7435(03)00048-3

Moore, L.L., Nguyen, U.S. Rothman, K.J., Cupples, L.A., and Ellison, R.C. (1995). Preschool physical activity level and change in body fatness in young children. The Framingham children's study. *Am J Epidemiol. 142(9,)* 982-988. https://doi.org/10.1093/oxfordjournals.aje.a117747

Mortensen, L.H., Siegler, I.C , Barefoot, J.C., Grønbaek, M., and Sørensen, T.I. (2008). Prospective associations between sedentary lifestyle and BMI in midlife. *Obesity (Silver Spring). 14(6),* 1462-1471. https://doi.org/10.1038/oby.2006.166

Mourier, A., Gautier, J-F., De Kerviler, E., Bigard, A.X., Villette, J-M., Garnier, J-P. et al. (1997). Mobilization of visceral adipose tissue related to the improvement in insulin snesitivity in response to physical training in NIDDM. *Diabetes Care. 20(3),* 385-391. https://doi.org/10.2337/diacare.20.3.385

Mozaffarian, D., Hao, T., Rimm, E.B., Willett, W.C., and Hu, F.B. (2011). Changes in diet and lifestyle and long-term weight gain in women and men. *N Engl J Med. 364(25),* 2392-2394. https://doi.org/10.1056/NEJMoa1014296

Muto, T., and Yamauchi, K. (2004). Evaluation of workplace health promotion: a multicomponent program conducted in Japan for improving employees' cardiovascular risk factors. *Pre Med. 33(6)*, 571-577 .https://doi.org/10.1006/pmed.2001.0923

Myers, A., Gibbons, C., Finlayson, G., and Blundell, J. (2017). Associations among sedentary and active behaviors, body fat and appetite dysregulation: investigating the myth of physical inactivity and obesity. *Br J Sports Med. 51(21)*, 1540-1544. https://doi.org/10.1136/bjsports-2015-095640

Neumark-Sztainer, D., Story, M., Hannan, P.J., and Rex, J. (2003). New Moves; a school-based obesity prevention program for adolescent girls. *Prev Med. 37(1),* 41-51. https://doi.org/10.1016/S0091-7435(03)00057-4

Nicklas, B.J., Chinelo, E., Delbono, O., Carr, J.J., Lyles, M.F., and Marsh, A.P. (2015). Effects of resistance training with and without caloric restriction on physical function and mobility in overweight and obese older adults: a randomized controlled trial. *Am J Clin Nutr. 101(5),* 991-999. https://doi.org/10.3945/ajcn.114.105270

O'Loughlin, J., Gray-Donald, K., Paradis, G , and Meshefedjian, G. (2000). One- and two-year predictors of excess weight gain among elementary schoolchildren in multiethnic low-income inner city neighborhoods. *Am J Epidemiol. 152(8)*, 739- 746. https://doi.org/10.1093/aje/152.8.739

Owens, J.F., Matthews, K.A., Wing, R.R., and Kuller, L.H. (1992). Can physical activity mitigate the effects of aging in middle-aged women? *Circulation. 85(4)*, 1265- 1270. https://doi.org/10.1161/01.CIR.85.4.1265

Owens, S., Gutin, B.A., Allison, J., Riggs, S., Ferguson, M., Litaker, M., and Thompson, W.C. (1999). Effect of physical training on total and visceral fat in obese children. *Med Sci Sports Exerc. 31(1)*, 143-148. https://doi.org/10.1097/00005768-199901000-00022

Paeratakul, S., Popkin, B.M., Keyou, G., Adair, L.S., and Stevens, J. (1998). Changes in diet and physical activity affect the body mass index of Chinese adults. *Int J Obes Relat Metab Disord. 22(5)*, 424-431. https://doi.org/10.1038/sj.ijo.0800603

Pangrazi, R.P., Beighle, A., Vehige, T., and Vack, C. (2003). Impact of promoting lifestyle activity for youth (PLAY) on children's physical activity. *J Sch Health. 73(8),* 317-321. https://doi.org/10.1111/j.1746-1561.2003.tb06589.x

Parizková, J. (1998). Treatment and prevention of obesity by exercise in Czech children. In: J. Pariková and A.P. Hills (eds.), *Physicsl fitness and nutrition during growth*. Basel, Switzerland, S. Karger, pp. 145-154. https://doi.org/10.1159/000061752

Park, S.K., Park, J-H., Kwon, Y-C., Kim, H.S., Yoon, M-S., and Park, H-T. (2003). Effect of combined aerobic and resistance exercise training on abdominal fat in middle-aged women. *J Physiol Anthropol. 22(3)*,129-135. https://doi.org/10.2114/jpa.22.129

Parker, D.R., Gonzalez, S., Derby, C.A, Gans, K.M., Lasater, T.M., and Carleton, R.A. (1997). Dietary factors in relation to weight change among men and women from two southeatern New England communities. *Int J Obes. 21*, 103-109. https://doi.org/10.1038/sj.ijo.0800373

Pate, R.R., Ward, D.S., Saunders, R.P., Felton, G., Dishman, R.K., and Dowda, M. (2005). Promotion of physical activity among high-school girls. A randomized controlled trial. *Am J Publ Health. 95(9),* 1582-1587. https://doi.org/10.2105/AJPH.2004.045807

Patrick, K., Calfas, K.J., Norman, G.J., Zabinski, M.F., Sallis, J.F., Rupp.J., Covin, J., and Cella, J. (2006). Randomized controlled trial of a primary care and home- based intervention for physical activity and nutrition behaviors. *Arch Pediatr Adolesc Med. 160(2)*, 128-136. https://doi.org/10.1001/archpedi.160.2.128

Pearalta, L.R., Jones, R.A., and Okely, A.D. (2009). Promoting healthy lifestyles amongadolescent boys. The fitness improvement lifestyle awareness program RCT. *Prev Med. 48(6),* 537-542. https://doi.org/10.1016/j.ypmed.2009.04.007

Polley, B.A., Wing, R.R., and Sims, C.J. (2002). Randomized controlled trial to prevent excessive weight gain in pregnant women. *Int J Obes Relat Metab Disord. 26(11),* 1494-1502. https://doi.org/10.1038/sj.ijo.0802130

Proctor, M.H., Moore, L.I., Gao, D., Cupples, L.A., Bradlee, M.L., Hood, M.Y., and Ellison, R.C. (2003). Television viewing and change in body fat from preschool to early adolescence: The Framingham Children's Study. *Int J Obes Relat Metab Disord. 27*, 827-833. https://doi.org/10.1038/sj.ijo.0802294

Proper, K.I., Hildebrandt, V.H., Van der Beeek, A.J., Twisk, J.W.R., and Van Mechelen, W. (2003). Effect of individual counseling on physical activity, fitness and health: a randomized controlled trial in a workplace setting. *Am J Prev Med. 24(3)*, 218-226. https://doi.org/10.1016/S0749-3797(02)00645-1

Puder, J.J., Vidal, P.M., S,chindler, C., Zahner, L., Niederer, I., Bürgi, F., et al. (2011). Effect of multidimensional lifestyle intervention on fitness and adiposity in predominantly migrant preschool children (Ballabeina): cluster randomized controlled trial. *Br Med J. 343*: d6195.https://doi.org/10.1136/bmj.d6195

Qi, Q., Li, Y., Chomistek, A.K., Kang, J.H., Curhan, G.C., Pasquale, L.R., et al. (2012). Television watching, leisure time physical activity and the genetic predisposition in relation to body mass index in women and men. *Circulation. 126(15),* 1821-1827. https://doi.org/10.1161/CIRCULATIONAHA.112.098061

Rainwater, D.L., Mitchell, B.D., Comuzzie, A.G., VandeBurgh, J.L., Stern, M.P., and Maccluer, J.W. (2000). Association among 5-year changes in weight, physical activity, and cardiovascular disease risk factors in Mexican Americans. *Am J Epidemiol. 152(10)*, 974-982. https://doi.org/10.1093/aje/152.10.974

Rauber, S.B., Castro, H.O., Marinho, A., Vicente, J.B., Ribeiro, H.L., Monteiro, L.Z., et al. (2018 ). Effects of a physical activity and nutritional intervention in overweight and obese children through an educational and recreational camp. *Nutr Health. 24(3),* 145-152. https://doi.org/10.1177/0260106018771519

Raustorp, A., Mattsson, E., Svensson, K., and Ståhle, A. (2006). Physical activity, body composition and physical self-esteem: a 3-year follow-up study among adolescents in Sweden. *Scand J Med Sci Sports. 16(4),* 258-266. https://doi.org/10.1111/j.1600-0838.2005.00483.x

Raynor, D.A., Phelan, S., Hill, J.O., and Wing, R.R. (2006). Television viewing and long-term weight maintenance: results from the National Weight Control Registry. *Obersity (Silver Spring). 14(10),* 1816-1824. https://doi.org/10.1038/oby.2006.209

Reed, K.E., Warburton, D.E.R., Macdonald, H.M., Naylor, P.J., and McKay, H.A. (2008). Action Schools! BC: A school-based physician activity intervention designed to reduce cardiovascular disease risk factors in children. *Prev Med. 46(6)*, 525-531. https://doi.org/10.1016/j.ypmed.2008.02.020

Reichkendler, M.H., Auerbach, P., Rosenkilde, M., Christensen, A.N., Holm, S., Petersen, M.B., et al. (2013). Exercise training favors increased insulin-stimulated glusoce uptake in skeletal muscle in contrast to adipose tissue: a randomized study usng FDG PET imaging. *Am J Physiol. 305(4),* E496-E506. https://doi.org/10.1152/ajpendo.00128.2013

Reilly, J.J., Kelly, L., Montgomery, C., Williamson, A., Fisher, A., McColl, J.H., et al.. (2006). Physical activity to prevent obesity in young children: cluster randomised controlled trial. *Br Med J. 333(7577): 1041.* https://doi.org/10.1136/bmj.38979.623773.55

Riddoch, C., Leary, S.D., Ness, A.R., Blair, S.N., Deere, K., Mattocks, C., Griffiths, A., et al. (2009). Prospective associations between objective measures of physical activity and fat mass in 12-14-year old children: the Avon longitudinal study of parents and children (ALSPAC). *BMJ, 339:b4544.* https://doi.org/10.1136/bmj.b4544

Rissanen, A.M., Heliövaara, M., Knekt, K., Reunanen, A., and Aromaa, A. (1991). Determinants of weight gain, and overweight in adult Finns. *Eur J Clin Nutr. 45(9)*, 419-430.

Robinson, T.N., Killen, J.D., Kraemer, H.C., Wilson, D.M., Matheson, D.M., Haskell, W.L., et al. (2003). Dance and reducing television viewing to prevent weight gain in African-American girls:the Stanford GEMS pilot study. *Ethnic Dis. 13(1 Suppl. 1),* S65-S77. PMID: 12713212

Rodearmel, D.J., Wyatt, H.R., Barry, M.J., Dong, F., Pan, D., Israel, R.G., et al. (2006). A family-based approach to preventing excessive weight gain. *Obesity. 14(8),* 1392- 1401. https://doi.org/10.1038/oby.2006.158

Ross, R., Dagnone, D., Jones, P.J.H., Smith, H., Paddags, A., Hudson, R., and Janssen, I. (2000). Reduction in obesity and related comorbid conditions after diet-induced weight loss, or exercise-induced weight loss in men. A randomized controlled trial *Arch Intern Med. 133,* 92-103. https://doi.org/10.7326/0003-4819-133-2-200007180-00008

Ruppenthal, B., and Gibbs, E. (1979). Treating childhood obesity in a public school setting. *J Sch Health. 49(10),* 589-571. https://doi.org/10.1111/j.1746-1561.1979.tb07686.x

Ruzic, L., Sporis, G., and Matkovic, B.R. (2007). High volume low intensity exercise camp and glycemic control in diabetic children. *J Pediatr Child Health. 44(3),* 122- 128. https://doi.org/10.1111/j.1440-1754.2007.01213.x

Sahota, R. , Rudolf, M.C.J., Dixey, R., Hill, A.J., Barth, J.H., and Cade, J. (2004).

Randomised controlled trial of primary school based intervention to reduce risk factors for obesity. *BMJ. 323(7320)*, 1029-1032. https://doi.org/10.1136/bmj.323.7320.1029

Sallis, J.F., McKenzie, T.L., Conway, T.L., Elder, J.P., Prochska, J.J., Brown, M., et al. (2003). Environmental interventions for eating and physical activity. A randomized controlled trial in middle schools. *Am J Prev Med. 24(3),* 209-217. https://doi.org/10.1016/S0749-3797(02)00646-3

Sarrafzadegan, N., Talaei, M., Sadeghi, M., Mohammadifard, N., Taheri, M., Lotfidazehj, M., et al. (2014). Determinants of weight change in a longitudinal study of Iranian adults: isfahan cohort study. *Arch Iran Med. 17(8),* 539-544. https://doi.org/014178/AIM.004

Schmitz, K.H., Jacobs, D.R., Leon, A.S., Schreiner, P.J., and Sternfeld, B.(2000). Physical activity and body weight associations over ten years in the CARDIA study. Coronary artery risk development in young adults. *Int J Obes Relat Metab Disord. 24,* 395-403. https://doi.org/10.1038/sj.ijo.0801415

Schofield, L., Mummery, W.K., and Schofield, G. (2005). Effects of a controlled pedometer-intervention trial for low-active adolescent girls. *Med Sci Sports Exerc. 37(8)*, 1414-1420. https://doi.org/10.1249/01.mss.0000174889.89600.e3

Schwingshackl, L., Dias, S., Strasser, B., and Hoffmann, G. (2013). Impact of differing training modalities on athropometric and metabolic characteristics in overweight/obese subjects: A systematic review and network meta-analysis. *PLoS ONE, 8(12): e82853*. https://doi.org/10.1371/journal.pone.0082853

Seltzer, C.C., and Mayer, J. (1970). An effective weight control program in a public school system. *Am J Publ Health. 60(4)*, 679-689. https://doi.org/10.2105/AJPH.60.4.679

Seo, Y-G., Lim, H., Kim, Y.M., Ju, Y.S., Lee, H.J., Jang, H.B., Park, S.I., and Park, K.H. (2019). The effect of a multidisciplinary lifestyle interventionj on obesity status, body composition, physical fitness, and cardiometabolic risk factors in children and adolescents with obesity. *Nutrients. 11(1):e137*. https://doi.org/10.3390/nu11010137

Shephard, R.J. (2019a). Can regular physical activity prevent obesity? 1. Potential factors reducing the efficacy of physical activity. *Health Fitness J Canada: In press.*

Shephard, R.J. (2019b). Can regular physical activity prevent obesity? 2, Empirical cross-sectional evidence of efficacy *Health Fitness J Canada, In press.*

Shephard, R.J. (2019). Is there a 'recent occupational paradox' where highly active physically active workers die early? Or arethere failures in some study methods? *Br J Sports Med*. In press.

Shephard, R.J., and Rode, A. (1996). *The health consequences of 'modernization.' Evidence from circumpolar peoples.* Cambridge, UK, Cambridge University Press, pp. 1-306. https://doi.org/10.1017/CBO9780511983726

Shephard, R.J., and Lavallée, H. (1993). Impact of enhanced physical education in theprepubescent child: Trois Rivières revisited. *Ped Exerc Sci. 5(2),* 177-189. https://doi.org/10.1123/pes.5.2.177

Sherwood, N.E., Jeffery, P.W., French, S.A., Hannan, P.J., and Murray, D.M. (2000). Predictors of weight gain in the pound of flesh prevention study. *Int J Obes Relat Metab Dis. 24,* 395-403. https://doi.org/10.1038/sj.ijo.0801169

Sigmund, E., Ansari, W.E., and Sigmundová, D. (2012). Does school-based physical activity decrease overweight and obesity in children aged 6-9 years? A two-year non-randomized longitudinal intervention study in the Czech Republic. *BMC Publ Health. 12: 570*. https://doi.org/10.1186/1471-2458-12-570

Sijtsma, A., Sauer, P.J.J, Stolk, R.P., and Corpeleijn, E. (2013). Infant movement opportunities are related to early growth- GECKO Drenthe cohort. *Early Hum Dev. 89(7),* 457-461. https://doi.org/10.1016/j.earlhumdev.2013.04.002

Silva, M.N., Vieira, P.N., Coutinho, S.R., Minderico, C.S., Matos, M.G., Sardinha, L.B., and

Teixeira, P.J. (2010). Using self-determination theory to promote physical activity and weight control: a randomized controlled trial in women. *J Behav Med. 33(2),* 110-122. https://doi.org/10.1007/s10865-009-9239-y

Simkin-Silverman, L.R., Wing, R.R., Boraz, M.A., and Kuller, L.H. (2003). Lifestyle intervention can prevent weight gain during menopause: results from a 5-year randomized clinical trial. *Ann Behav Med. 26(3),* 212-220. https://doi.org/10.1207/S15324796ABM2603_06

Simon, C., Schweitzer, B., Oujaa, M., Wagner, A., Arveiler, D., Triby, E., et al. (2008). Successful overweight prevention in adolescents by increasing physical activity: a 4-year randomized controlled intervention. *Int J Obes. 32,* 1489-1498. https://doi.org/10.1038/ijo.2008.99

Slentz, C.A., Duscha, B.D., Johnson, J.L., Ketchum, K., Aiken, L.B , Samsa, G.P., et al. (2004). Effects of the amount of exercise on body weight, body composition and measures of central obesity. STRRIDE: a randomized controlled study. *Arch Int Med. 164(1),* 31-39. https://doi.org/10.1001/archinte.164.1.31

Sobol-Goldberg, S., Rabinowitz, J., and Gross, R. (2013). School-based obesity prevention programs: A meta-analysis of randomized controlled trials. *Obesity. 21(12),* 2422-2428. https://doi.org/10.1002/oby.20515

Sollerhed, A.C., and Ejlertson, G. (2008). Physical benefits of expanded physical education in primary school: findings from a 3-year intervention study in Sweden. *Scand J Med Sci Sports. 18(1),* 102-107. https://doi.org/10.1111/j.1600-0838.2007.00636.x

Sprynarová, S., and Parizková, J. (1965). Changes in the aerobic capcacity and body composition in obese boys after reduction. *J Appl Physiol. 20(5),* 934-937. https://doi.org/10.1152/jappl.1965.20.5.934

Staiano, A.E., Martin, C.K., Champagne, C.M., Rood, J.C., and Katzmarzyk, P.T. (2018). Sedentary time, physical activity and adiposity in a longitudinal study of nonobese young adults. *Am J Clin Nutr. 108(5),* 946-952. https://doi.org/10.1093/ajcn/nqy191

Story, M., Sherwood, N.E., Himes, J.H., Davis, M., Jacobs, D.R. , Cartwright, Y., Smyth, M., and Rochon, J. (2003). An after-school obesity prevention program for African-American girls: the Minnesota GEMS pilot study. *Ethn Dis, 13 (1 Suppl. 1)* S54-S64. PMID: 12713211

Story, M. S. (1999). School-based approaches for preventing and treating obesity. *Int J Obes. 23 (Suppl. 2),* S43-S51. https://doi.org/10.1038/sj.ijo.0800859

Stunkard, A.J., Berkowitz, R.I., Stallings, V.A., and Schoeller, D.A. (1999). Energy intake, not energy output, is a determinant of body size in infants. *Am J Clin Nutr. 69(3),* 524-530. https://doi.org/10.1093/ajcn/69.3.524

Tammelin, T., Laitinen, J., and Näyhä, S. (2004). Change in the level of physical activity from adolescence into adulthood and obesity at the age of 31 years. *Int J Obes Relat Metab Disord. 28,* 775-782. https://doi.org/10.1038/sj.ijo.0802622

Tanas, R., Marcolongo, R., Pedretti, S., and Gilli, G. (2007). A family-based education program for obesity: a three year study. *BMC Pediatrics. 7:33.* https://doi.org/10.1186/1471-2431-7-33

Tataranni, P.A., Harper, I.T., Snitker, S., DelPangri, A, Vozarova, B., Bunt, J., et al. (2003). Body weight gain in free-living Pima Indians: effect of energy intake vs. expenditure. *Int J Obes Relat Metab Disord. 27(9),* 1578-1583. https://doi.org/10.1038/sj.ijo.0802469

Taylor, C.B., Jatulis, D.E., Winkleby, M.A., Rockhill, B.J., and Kraemer, H.C. (1994). Effects of lifestyle on body mass index change. *Epidemiology. 5(6),* 599-603. https://doi.org/10.1097/00001648-199411000-00007

Taylor, R.W., McAuley, K.A., Barbezat, W., Strong, B.A., Williams, S.M., and Mann, J.I. (2007). APPLE PROJECT: 2y findings of a community-based obesity prevention program in primary school-age children. *Am J Clin Nutr. 86(3),* 735-742. https://doi.org/10.1093/ajcn/86.3.735

Thivel, D., Masurier, J., Baquet, G., Timmons, B.W., Pereira, B., Berthoin, S. Duclos, M., and Aucouturier, J. (2019). High interval training in overweight and obese adolescents: systematic review and meta-analysis. *J Sports Med Phys Fitness. 59(2)*, 310-324. https://doi.org/10.23736/S0022-4707.18.08075-1

Tieland, M., Dirks, M.L., van der Zwaluw, N., Verdijk, L.B., van de Rest, O., de Groot, L.C., and van Loon, L.J. (2012). Protein supplementation increases muscle gain during prolonged resistance-type exercise training in frail elderly people: A randomized placebo-controlled trial. *J Am Med Dir Assoc. 13(8)*, 713-719. https://doi.org/10.1016/j.jamda.2012.05.020

Timmons, B.W., LeBlanc, A.G., Carson, V., Gorber, S.C., Dillman, C., Janssen, I., et al. (2012). Systematic review of physical activity and health in the early years (ages 0-4 years). *Appl Physiol Nutr Metab. 37(4)*, 773-792. https://doi.org/10.1139/h2012-070

Treuth, M.S., Butte, N.F., and Sorkin, J.D. (2003). Predictions of body fat gain in non-obese girls with a familial predisposition to obesity. *Am J Clin Nutr. 78(6),* 1212-1218. https://doi.org/10.1093/ajcn/78.6.1212

Vahlberg, B., Lindmark, B., Zetterberg, L., Hellström, K., and Cederholm, T. (2017). Body composition and physical function after progressive resistance and balance training among older adults after stroke. *Disabil Rehab. 39(12),* 1207-1214. https://doi.org/10.1080/09638288.2016.1191551

Vandongen, R., Jenner, D.A , Thompson, C., Taggart, A.C., Spickett, E.E., Burke, V., et al. (1996). A controlled evaluation of a fitness and nutrition intervention program on cardiovascular health in 10- to 12-year-old children. *Prev Med. 24(1),* 9-22. https://doi.org/10.1006/pmed.1995.1003

Verheggen, R.J., Maessen, M.F., Green, D.J., Hermus, A.R., Hopman, M.T., and Thijssen, D.H. (2016). A systematic review and meta-analysis of the effects of exercise training versus hypocaloric diet: distinct effects on body weight and visceral adipose tissue. *Obes Rev. 17(8)*, 664-690 .https://doi.org/10.1111/obr.12406

Villareal, D.T., Banks, M., Sinacore, D.R., Siener, C., and Klein, S. (2006). Effect of weight loss and exercise on frailty in obese older adults. *Arch Intern Med. 166(8),* 860-866. https://doi.org/10.1001/archinte.166.8.860

Vissers, D., Hens, W., Taeymans, J., Baeyens, J-P., Poortmans, J., and Van Gaal, L. (2013). The effect of exercise on visceral adipose tissue in overweight adults: A systematic review and meta-analysis. *PLoS ONE, 8(2): e56415*. https://doi.org/10.1371/journal.pone.0056415

Vizcaíno, M., Aguilar, F.S., Gutiérrez, R.F., Maretínez, M.S., Lőpez, M.S., Martínez, S.S., García, L.E., and Artalejo, F.R. (2008). Assessment of an after-school program to prevent obesity among 9- to 10-year-old children: a cluster randomized trial. *Int J Obes. 32(1)*, 12-22. https://doi.org/10.1038/sj.ijo.0803738

Voorrips, L.F., Meijers, J.H., Sol, P, Seidell, J.C., and. van Staveren, W.A.(1991). History of body weight and physical activity of elderly women differing in current physical activity. *Int J Obes Rel Metab Disord. 16(3),* 199-205. PMID: 1317829

Vioque, J., Torres, A., and Quiles, J. (2000). Time spent watching television, sleep duration and obesity in adults living in Valencia, Spain. *Int J Obes Relat Metab Disord, 24(12),* 1683-1688. https://doi.org/10.1038/sj.ijo.0801434

Wafa, S.W., Talib, R.A., Hamzaid, N.H., McColl, J.H., Rajikan, R., Ng, L.O., Ramli, A.H., and Reilly, J.J. (2011). Randomised controlled trial of a good practice approach to treatment of childhood obesity in Malaysia: Malaysian childhood obesity treatment trial (MSASCOT). *Int J Pediatr Obes. 6:e62-e69.* https://doi.org/10.3109/17477166.2011.566340

Wagner, A., Simon, C., Ducimitière, P., Montaye, M., Bongard, V., Yarnell, J., et al. (2001). Leisure time physical activity and regular walking or cycling to work are associated with adiposity and 5-year weight gain in middle-aged men; the PRIME study. *Int J Obes. 25*, 940-948. https://doi.org/10.1038/sj.ijo.0801635

Wake, M., Baur, L.A., Gerner, B., Gibbons, K., Gold, L., Gunn, J., et al. (2009). Outcomes and costs of primary care surveillance and intervention for overweight or obese children: the LEAST 2 randomised controlled trial. *Br Med J. 339:b3308* https://doi.org/10.1136/bmj.b3308

Wanner, M., Martin, B.W., Autenrieth, C., Schaffner, E., Meier, F., Brombach, C.,, et al. (2016). Associations between domains of physical activity, sitting time and different measures of overweight and obesity. *Prev Med Rep. 3*, 177-184. https://doi.org/10.1016/j.pmedr.2016.01.007

Wareham, N.J., van Sluijs, E.M.F., and Ekelund, U. (2005). Physical activity and obesity prevention: a review of the current evidence. *Proc Nutr Soc. 64(2),* 229-247. https://doi.org/10.1079/PNS2005423

Warren, MJ.M., Henry, C.J.K., Lightowler, H.J., Bradshaw, S.M., and Perwaiz, S. (2003). Evaluation of a pilot school programme aimed at the prevention of obesity in children. *Health Prom Internat. 18(4),* 287-296. https://doi.org/10.1093/heapro/dag402

Waters, E., de Silva-Sanigorski, A., Burford, B.J., Brown, T., Campbell, K.J., Gao, Y., etal. (2011). Interventions for preventing obesity in children (Review). *Cochrane Data Base of Systematic Reviews. 12: Art CD001871* https://doi.org/10.1002/14651858.CD001871.pub3

Webber, L., Catellier, D.J., Lytle, L.A., Murray, D.M., Pratt, C.A., Young, D.R., et al. (2008). Promoting physical activity in middle school girls. Trial of activity for adolescent girls. *Am J Prev Med. 34(3),* 173-184. https://doi.org/10.1016/j.amepre.2007.11.018

Weintraub, D.L., Irumalai, E.C., Haydel, K.F., Fujimoto, M., Fulton, J.E., and Robinson, T.N. (2008). Team sports for overweight children. The Stanford sports to prevent obesity randomized trial (SPORT). *Arch Pediatr Adolesc Med. 162(3),* 232-237. https://doi.org/10.1001/archpediatrics.2007.43

Wells, J.C.K., and Ritz, P. (2001). Physical activity at 9-12 months and fatness at 2 years of age. *Am J Hum Biol. 13(3),* 384-389. https://doi.org/10.1002/ajhb.1062

Williamson, D.E., Madans, J., Anda, R.F., Kleinman, J.C., Kahn, H.S., and Byers, T. (1993). Recreational physical activity and ten-year weight change in a US national cohort. *Int J Obes Relat Metab Disord, 17(5)*, 279-286. PMID: 8389337

Wood, P.D., Haskell, W.L., Blair, S.N., Williams, P.T., Krauss, R.M., Lindgren, F.T., et al. (1983). Increased exercise level and plasma lipoprotein concentrations. A one-year randomized, controlled study in sedentary middle-aged men. *Metabolism. 32(1)*, 31-39. https://doi.org/10.1016/0026-0495(83)90152-X

Yassine, H.N., Marchetti, C.M., Krishnan, R.K., Vrobel, T.R., Gonzalez, F., and Kirwan, J.P. (2000). Effects of exercise and caloric restriction on insulin resistance and cardiometabolic risk factors in older obese adults- a randomized clinical trial. *J Gerontol Med Sci. 61A(1)*, 90-95. https://doi.org/10.1093/gerona/gln032

Zakus, G., Chin, M.L., Cooper, H., Makovsky, E., and Merrill, C. (1981). Treating adolescent obesity: a pilot project in a school. *J Sch Health. 51(10),* 663-666. https://doi.org/10.1111/j.1746-1561.1981.tb02118.x

Zhang, H., Tong, T.K., Qiu, W., Zhang, X., Zhou, S., Liu, Y., and He, Y. (2017). Comparable effects of high intensity interval training and prolonged continuous exercise training on abdominal fat reduction in obese young women. *J Diabetes Res. ID5071740.* https://doi.org/10.1155/2017/5071740

Zurlo, F., Ferraro, R.T., Fontvielle, A.M., Rising, R., Bogardus, C., and Ravussin, E. (1992). Spontaneous physical activity and obesity: cross-sectional and longitudinal studies in Pima Indians. *Am J Physiol. 263(2),* E296-E300. https://doi.org/10.1152/ajpendo.1992.263.2.E296

Zwiauer, K.F.M. (2000). Prevention and treatment of overweight and obesity in children and adolescents. *Eur J Pediatr. 159(Suppl. 1),* S56-S68. https://doi.org/10.1007/PL00014367