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NARRATIVE REVIEW

Can Regular Physical Activity Prevent Obesity? Part 2: Empirical cross-sectional evidence of efficacy.

Roy J. Shephard^{1,*}

1 Faculty of Kinesiology & Physical Education, University of Toronto, ON, Canada.

***Corresponding Author:** royjshep@shaw.ca

Abstract

Objective: The objective of this narrative review is to examine cross-sectional empirical data suggesting the efficacy of adequate daily physical activity in the prevention of obesity. **Methods:** Information obtained from Ovid/Medline and Google Scholar through to March 2019 was supplemented by a search of the author's extensive personal files. **Results:** Average skin-fold readings are often as low as 5 mm, in male elite long-distance competitors who spend many hours per week in training, and values for female endurance competitors are also often only a half of those found in the general female population. Physical education (PE) students (particularly men) are somewhat thinner than their peers in other faculties, but this advantage is attenuated in averaged data because a proportion of PE students have a lesser commitment to an active lifestyle, and also some students in other faculties engage in physically demanding inter-collegiate sports. Early occupational studies showed low body fat levels in physically active occupations, and a similar difference can still be observed in elite military groups where high daily energy expenditures are required. Amish and Old-order Mennonite families who eschew modern mechanical devices have very high levels of daily physical activity, and this is reflected in their correspondingly low levels of body fat. Similar findings have been reported for Inuit who still follow a hunter-gatherer lifestyle. Studies validating questionnaires and accelerometers in the general population have show correlations of up to -0.50 between scores on such instruments and estimates of body fat content. Finally, cross-sectional comparisons within circumpolar communities have demonstrated higher levels of aerobic fitness in those populations with the least acculturation to a sedentary "white" lifestyle, and this sub-group of circumpolar residents also has a low body fat content. **Conclusions:** Conclusions about the impact of vigorous daily physical activity upon body fat content are limited by the possible self-selection of a physically active lifestyle, with the adoption of other favorable health behaviours by active individuals. Nevertheless, all of numerous population comparisons show lower levels of body fat in those groups who maintain an adequate level of habitual physical activity. In some cases, the levels of physical activity adopted have been very high, but there are also examples of populations where a favourable body composition has been associated with the regular performance of volumes of physical activity that are appropriate for average middle-aged adults. **Health & Fitness Journal of Canada 2019;12(2):64-96.**

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Introduction

Many nutritionists have argued over the years that regular physical activity is unlikely to be effective in the prevention or the treatment of obesity (Epstein & Wing, 1980; Jakicic, Clark, & Coleman, 2001; Malhotra & Noakes, 2015; Shaw, Gennat, & O'Rourke, 2006). Such authors have pointed to the large total volume of energy expenditure needed to reduce body fat content significantly, the likely stimulation of appetite by vigorous exercise, and a possible reduction of both resting metabolic rate and spontaneous physical activity that counters the therapeutic response to both dieting and vigorous exercise. A companion article (Shephard, 2019) has recently examined (and largely dismissed) these arguments. The present narrative review offers empirical cross-sectional evidence suggesting that an adequate level of habitual physical activity is consistently associated with low levels of body fat in a wide variety of populations. Subsequent articles will substantiate this view with prospective data showing substantial favourable changes of body composition in response to regular participation in an exercise programme, and will then explore the role of exercise programmes in the more intractable problem of treating established obesity.

When looking at reasons behind a trim body figure, investigators inevitably face the perennial problem of disentangling the closely intertwined influences of physical activity, a well-regulated diet, other facets of a healthy lifestyle, and a genetic predisposition to a low body fat content among those who have achieved and maintain an appropriate body build (Shephard, 2018). We will here look critically at evidence derived from various cross-sectional studies that have related

habitual physical activity to body fat content, including comparisons between the general population and supposedly active groups such as endurance athletes, participants in other long-distance and ultra-long distance events (Table 1), physical education students, workers in physically demanding jobs, traditional Amish farmers and unacculturated Inuit. We will also look at cross-sectional associations between self-reported or objectively measured habitual physical activity and obesity levels in the general population, and will compare the body composition of indigenous populations at various stages in their adoption of a sedentary western lifestyle.

Endurance athletes vs. the general population

There are occasional groups of athletes such as Sumo wrestlers, where the accumulation of fat apparently gives them a competitive advantage, but most athletes body fat quickly accumulates if training is interrupted by injury, and some of the thinnest athletes are those such as ultra-marathoners who engage in many hours of endurance training each day.

An early analysis of 6 studies of elite male distance runners showed body fat

Table 1: Weighted average of body fat content (% fat) as reported for elite endurance athletes (Shephard and Åstrand, 2000).

Sport	Male competitors	Female competitors
Canoeing	11.2	
Cycling	8.6	15.4
Cross country skiing	7.9	15.7
Distance running	4.7	16.3
Rowing	8.5	14.0
Soccer	10.3	21.0
Swimming	11.6	18.6
Triathlon	9.0	14.1

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Table 2: Estimated body fat percentage in various groups of distance runners.

Authors	Sample	Measure of body fat	
		Males	Females
Arrese & Ostáriz (2006)	42 M, 22 F elite runners, Sum of 6 skin-folds, 3 km, 10 km, and marathoners	35.9, 38.4, 31.2 mm	61.7, 50.4, 44.4 mm,
Arazi et al. (2012)	160 phys ed., 170 other male students	14.1% (PE) 21.1% (other)	
Arazi & Hoseini (2011)	140 student athletes, 160 other female students		BMI 21.5 vs. 25.2 kg/m ²
Bale et al. (1986)	20 elite male 10 km runners	8.0% fat	
Bartlett et al. (1984)	10 collegiate-level female distance runners		14.8% fat
Coetzer et al. (1993)	9 white, 11 black runners (? male) over distances > 3km.	Average skin-fold 6.3 mm vs. 5.0 mm	
Conley & Krahenbuhl (1980)	12 male 10 km runners	Average skin-fold 5.3 mm	
Costill et al. (1970)	114 participants in 1968 US marathon trial	7.5% by 3 skin-fold equations (12.5% in other students)	
Cureton et al. (1978)	4 men, 2 women, distance runners	9.4%	20.8%
de Garay et al. (1974)	34 male distance runners	-0.5%	
Eksterowicz et al. (2016)	9 Kenyan male distance & marathon runners	5.4%	
Flack (1983)	14 U.S. marathon runners	6.4%	
Graves et al. (1987)	15 elite and 12 good female distance runners		14.3% (elite) 16.8% (good)
Hirata et al. (1966)	99 male Tokyo Olympic participants	1.4%	
Knechtle et al. (2015)	42 female Recreational half-marathon runners		27.2%
Kong & de Heer (2008)	6 male Kenyan distance runners	5.3%	
Pollock et al. (1977)	11 distance, 8 marathon runners (male)	5.0% (distance) 4.3% (marathon)	
Rusko et al. (1978)	8 top distance male runners	8.4%	
Sprynarová & Parizková (1971)	10 top ? male runners, distance not specified	6.4%	
Upton et al. (1983)	38 female middle-aged marathoners vs. 35 sedentary controls		15.6% vs. 27.8%
Vaccaro et al. (1981)	10 female distance runners (Masters)		18.3%
Vernilio et al. (2013)	14 top male Kenyan runners	8.9%	
Wilmore et al. (1977)	42 female world class distance runners		16.9%
Wilmore & Brown (1974)	11 female National level distance runners		15.2%,

values ranging from -0.5% to 9.4%, with a weighted average of only 4.7% (Shephard

& Åstrand, 2000; Table 2). This figure stands in considerable contrast with

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typical values for healthy young North American adults (~15-22% in men, and ~22-28% in women, Lohman, 1992).

Detailed data on the body fat content of distance runners are summarized in Table 1. In addition to very low overall values, in general, the male/female body fat ratio is lower than in the general population, perhaps because a higher proportion of male competitors have a strong commitment to distance running.

Looking at details of some of the individual studies, Arrese & Ostáriz (2006) reported values for a group of highly trained runners (130 men and 54 women) who were competing over various distances. Focusing on the distance competitors, data averaged across 6 skin-folds showed values of only 5-6 mm in the men, and 7-10 mm in the women, as compared with averages of 8 and 10 mm for young men and women from the general population in Toronto (Shephard, 1979). In both sexes, the skin-fold thickness was inversely related to the athlete's competitive distance, and the lowest readings were seen in the marathoners.

Bale et al. (1986) examined 60 male 10 km runners at various levels of proficiency. In the 20 elite competitors, who presumably were the most heavily committed to training, the skin-fold predictions of body fat content averaged 8.0%, while the thickness of 5 measured skin-folds averaging 5 mm. However, in second and third rank competitors, body fat content was usually substantially greater, with average values of 10.7% and 12.1% respectively.

Bartlett et al. (1984) compared 10 female collegiate-level distance runners with 10 university gymnasts. The runners were taller than the gymnasts, and in both

groups the hydrostatic estimates of body fat (averages of 14.8% and 16.8%, respectively) were much lower than among the general population of university women.

Coetzer et al. (1993) compared body fat in 11 "black" and 9 "white" South Africans. Both groups were committed athletes, competing over distances >3 km, and engaging in 80-90 km of training per week. Averages of skin-fold readings taken at 7 measurement sites for these subjects were 5.0 and 6.3 mm, respectively. The "black" runners were not only systematically thinner ($p=0.012$), but also had had consistently higher speeds than their "white" competitors, mainly because they trained at a higher percentage of their maximal oxygen intakes, and thus had a lesser lactate accumulation during an event.

Conley & Krahenbuhl (1980) studied 12 of the top male finishers in a nationally known 10 km race. This highly trained group had an average maximal oxygen intake of 71.7 ml/[kg.min]. Skin-folds measured at 6 sites had an average thickness of only 5.3 mm. Inter-individual differences in performance among this group seemed due mainly to differences in running economy.

Costill et al. (1970) compared all 114 participants in the U.S. 1968 marathon trials with a group of 92 male university students who were not participating in any organized physical training programme, and 63 graduate students and faculty. Using the average of 3 different skin-fold predictions to determine body fat content, average values were 7.5% for the distance runners, compared with 12.5% for the non-athletic undergraduates and 16.3% for the graduate students and faculty members. It was estimated that despite a relatively low total body mass,

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the runners had energy expenditures as high as 25MJ/day.

Cureton et al. (1978) reported data for 4 male and 2 female distance runners; although their subjects engaged in regular training, they were less fit than some of the other groups discussed in this section, with maximal oxygen intakes of ~58 ml/[kg.min] for the men, and ~49 ml/[kg.min] for the women. Body fat was determined by underwater weighing, and the respective estimates of 9.4% and 20.8% were somewhat lower than in the general population. Cureton et al. noted that any experimental additions to body mass led to corresponding decreases in distance running performance.

De Garay et al. (1974) based their estimates of body fat in Olympic champions on somatotyping and a measurement of bone diameters. They obtained very low (and often puzzlingly low negative) estimates of body fat content in 44 male distance and marathon runners. Hirata (1966) used a similar methodology on 99 male Olympic champions in Tokyo, again obtaining very low values for the distance runners (an average of 1.4% fat).

Eksterowicz et al. (2016) examined the contribution of physical characteristics to the outstanding competitive performances of 9 male Kenyan distance and marathon runners. A skin-fold estimate of body fat content yielded an average of 5.4%, with the thickness of 3 skin-folds averaging the very low figure of 4.3 mm. Kong & de Heer (2008) had similar findings for a group of 6 male Kenyan distance runners, with a skin-fold estimate of 5.3% body fat. Vernilio et al. (2013) made a further study of 14 male Kenyan runners, finding a somewhat higher (although still very low) skin-fold prediction of fat (8.9%). This last study is the most recent, and it is possible

that the nutrition of the top Kenyan runners may have improved over the course of these 3 studies.

Flack (1983) used both hydrostatic and anthropometric methods to estimate the body fat content of 14 marathon runners who were among 528 elite U.S. male athletes attending the U.S. Olympic Training Center in Colorado Springs. The average skin-fold prediction of body fat content for this sample was 6.4%, although a higher value (12.5%) was obtained by hydrostatic weighing. Fleck noted that the lowest fat values were seen in athletic disciplines where a high maximal oxygen intake was required.

Graves et al. (1987) studied the body composition of 15 elite (international or national level) and 12 good (local level) female distance runners. The elite group had been running an average of 104 km/week during the previous year, and the good runners had covered 63 km/week during their training. The respective estimates of body fat by underwater weighing, at 14.8% and 16.3%, were low for women, and values for the "good" group were not significantly greater than those for the elite runners. Skin-fold and bio-impedance predictions both tended to underestimate the hydrostatic predictions in this sample.

The data of Knechtle et al. (2015) illustrate the importance of commitment to distance running. In a group of 42 unselected female recreational half-marathoners (participants in the Basel half-marathon), training distances were limited to an average of 32 km/week, or 3.6 hours of running per week, and a skin-fold prediction of body fat yielded the quite high average of 27.2%. The percentage of body fat was quite closely correlated with race times ($r = 0.56$), and was also correlated negatively with the

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weekly training distance ($r = 0.34$ to -0.69 for different skin-folds).

Pollock et al. (1977) made skin-fold and hydrostatic predictions of body fat in 11 elite (international or national class) long-distance and marathon runners, finding respective body fat levels of 5.0% and 4.3%, with figures of 5.2 and 5.8 mm for the average of 7 skin-folds. In "good" rather than elite runners, the average predicted body fat increased to 6.0%, and in "average": young men they found a skin-fold thickness of 6.5 mm

Rusko et al. (1978) studied athletes, about a half of whom were members of the Finnish national team. Skin-fold predictions of body fat in 8 male distance runners yielded an average of 8.4% body fat. They compared this figure to average values of 11.0% for 8 physical education students, and 14.4% for 23 male controls. The relative training status of the 3 groups can be inferred from their respective levels of maximal oxygen intake (78.1, 65.1 and 55, ml/[kg.min]).

Sprynarová & Parizková (1971) reported hydrostatic predictions of body fat in 10 top (presumably male) representative Czech runners (distance not specified; average maximal oxygen intake 64 ml/[kg.min]); values averaged 6.3% fat.

Upton et al. (1983) compared 38 middle-aged female marathoners (aged 31-50 years, who were currently training over an average distance of 74 km/week with 35 sedentary women. Differences in maximal oxygen intake indicated their respective levels of physical condition (55.5 and 31.4 ml/[kg.min]). Hydrometric estimates of body fat were 15.6% and 27.8%. Vaccaro et al. (1981) also studied older women, finding an average body fat of 18.3% in 10 female Masters runners with an average age of 44 years; their

body fat was still only some 40% of values found in controls of similar age.

Wilmore & Brown (1974) and Wilmore et al. (1977) used underwater weighing to determine the body fat in two samples of top (international or national level) female distance runners, finding values of 15.2% and 16.9% respectively, about 50% of the values that they observed in their control subjects. In 2 of the best female runners from this group, the body fat content was less than 6%. The maximal oxygen intake of the group averaged 59.1 ml/[kg.min], but in the thinnest individual a value of 71.1 ml/[kg.min] was observed.

In summary, various authors have consistently demonstrated very low skin-fold readings and predictions of body fat content in athletes, particularly in distance runners. Some of this association could be explained by constitutional factors, with those having a slim body build gravitating to running as their preferred sport. However, long-distance runners also engage in very large volumes of endurance activity, with energy expenditures in some cases as high as 25 MJ/day, and the contribution of this physical activity to low fat levels is strongly suggested by inverse relationships to several measures of daily energy expenditure: the individual's preferred competitive distance, the level of competition, and the maximal oxygen intake.

Participants in other distance and ultra-long-distance running events

In support of the evidence garnered from top endurance athletes, we may look also at body fat data obtained on distance runners of less than international standard, and other individuals who, although not highly selected athletes have engaged in exceptional bouts of sustained

physical activity, such as running coast-to-coast across Canada.

Other distance runners.

Farrell et al. (1979) studied 18 experienced male distance runners aged 28 years who had been competing for 1 to 10 years and had a maximal oxygen intake averaging 61.8 ml/[kg.min]. Hydrostatic weighing showed an average of 9.3% body fat in this group.

Lewis, Haskell, Klein, Halpern, & Wood (1975) collected hydrostatic data on 45 physically active middle-aged men (average age 47 years), most of whom were engaged in jogging programmes and were running distances >25 km/week; many supplemented their running with swimming, cycling and active games. Treadmill times averaged 16 minutes on the Bruce protocol, demonstrating an excellent level of fitness, and hydrostatic data showed an average of 13.2% body fat in this group.

Tudor-Locke et al. (2010) examined the NHANES data for a large sample of the general U.S. population, demonstrating differences of actigraph-measured step-counts collected for 1 waking day or longer between those with a normal BMI (8285 steps/day in men and 6486 steps/day in women), those who were overweight (7643 steps/day in men, 5482 steps/day in women) and those who were obese (BMI > 30 kg/m², 6664 steps/day in men, 5069 steps/day in women). It is important to note that all individuals in this sample were relatively inactive, and that the step counts associated with maintenance of a normal BMI were well within the capacity of the average middle-aged individual.

Ultra-long distance events.

One healthy 43-year-old woman ran a total of 7250 km across Canada (Mertens et al., 1996), covering an average of 65 km/day for 112 days at a typical pace of ~7.9 km/h. During the course of this journey, she metabolized 16.7 kg of tissue, 81.4% of which was fat. Clearly, in her case, the regular daily physical activity was very effective in reducing her immediate body fat content, although we have no information on how well this fat loss was sustained in subsequent years. A young man completed a similar run, and although he made strenuous efforts to maintain his nutrition over the journey, he also lost about 8 kg of weight, mainly fat (Shephard et al., 1975).

Schutz et al. (2012) described a Trans-European foot race, where 44 participants who had previously engaged in an average of 18 years of distance running covered a 4,486 km ultra-marathon. The bio-impedance estimate of body fat percentage, averaged across 40 men and 4 women, was 11.2% at the outset of this event.

Several other authors have reported observations on ultra-distance runners. A 60-year-old Quebec man ran 6400 km over a period of 4 months (Jobin, Tremblay, and Samson, 1984), reducing his body mass by 5.4 kg (mostly fat). Bioelectrical impedance analysis also showed a decrease of body fat content after a woman ran 1200 km over 17 days, although this change was not detectable in skin-fold measurements (Knechtle et al., 2008). Knechtle & Bircher (2005) had an athlete run for 6 days, finding that despite an increased intake of fat and protein during the run, there was a substantial loss of sub-cutaneous fat. Finally, a 320 km run across Switzerland, completed over 54 hours, and involving a 7000 m increase of

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altitude, led to a 1.02 kg loss of lean tissue and a 0.30 kg decrease of fat mass (Knechtle & Knechtle, 2007).

Physical education students vs. other university students

Comparisons of body fat content among university students have been based on either the individual's choice of faculty (physical education vs. other disciplines), or on questionnaire or objective measurements of actual activity patterns in the selected groups of students.

Choice of Faculty

During term-time, physical education (PE) students usually devote a substantial part of each week to learning the physical skills that will be needed in their profession. A typical programme may involve participation in 8 weekly one-hour practice in disciplines such as basketball, soccer, squash and tennis, and many students supplement such curricular requirements by vigorous training for one or more inter-collegiate sports teams. Thus PE students might be thought to offer useful evidence on the impact of several years of sustained and vigorous physical activity upon the body composition of a young adult. There is evidence of some selective recruitment, with more obese individuals avoiding PE as a career choice. Nevertheless, one might anticipate that the physical characteristics of the average PE student would reflect the effects of regular vigorous physical activity in containing the accumulation of body fat, despite the absence of any deliberate restrictions on the type and quantity of food ingested.

In general, the expectation of a low body fat content relative to students in other faculties is met, but there are some exceptions. One factor complicating the

analysis is a difference of entry grades between faculties. In prestigious universities, the minimum required high school academic grades tend to be less stringent for PE than for other faculties. Thus, individuals who are less intellectually gifted may opt to seek a placement in PE not because they have any strong personal commitment to physical activity, but rather because they view such a choice as an easy means of gaining access to a major university despite less than stellar high school marks. Such students tend to select physically less demanding practica within a physical education programme (classes in golf, archery, ballroom dancing and yoga, for example), and even in these activities they may invest the minimum amount of interest and physical effort required to obtain a passing grade.

Intensity of programme. Stachoń & Pietraszewska (2013) obtained evidence on the importance of programme intensity. They classified 252 male physical education students in terms of their apparent commitment to a high daily level of physical activity. Those members of the class who were rated as vigorously active had a significantly lower bio-impedance estimated percentage of body fat (19.6%) than those were classed as only moderately active (21.8%).

In addition to the student's personal commitment, a further potential issue affecting the intensity of daily effort is that in some PE programmes, the first year of instruction may focus on academic disciplines such as psychology and sociology. Thus, the initial physical demands on the student may be quite low, and even insufficient to maintain the level of physical condition observed at entry to university. For instance, Meckel et al.

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(2011) evaluated 85 male and 89 female Israeli physical education students on entry to the Wingate Institute and at the end of their freshman year. Over this introductory year, both sexes showed some evidence of a loss of physical fitness, with small increases in their percentages of body fat, and a parallel slowing in their speeds over a 2 km run. Moreover, the deterioration of physical condition was most marked in students who were fittest on admission to the programme.

Empirical data. A large number of investigators have reported empirical data on the body fat content of physical education majors (Table 3). Some investigations have shown relatively low levels of body fat, particularly in male students, but in other data sets the values for PE students have differed little from those found in students from other faculties.

A study of 161 male and 74 female students enrolled in a Polish physical education department (Smolarczyk et al., 2012) underlined two factors limiting the interpretation of such inter-faculty comparisons. There was a substantial element of programme self-selection, in that students who entered the PE classes were taller than their peers in other faculties. In general, the physical education students also had a greater mass of lean tissue, so that BMI values did not provide a very reliable basis for rating obesity levels. However, the men in the Polish PE programme also had a very low average body fat content as determined by bio-impedance measurements (an average of 12.5%). The average body fat in the women (21.5%) was not particularly high, although a third of the female PE students in this study had more than 25% body fat.

In one of the earliest studies of a PE programme, Shephard & Pimm (1975) evaluated a substantial sample of third-year students (68 men and 74 women) who were attending the University of Toronto. Some of the students in this group were enthusiastic athletes, but other individuals seemed to have chosen the faculty of PE not because of a strong personal interest in fitness, but rather because they thought that it offered them a means of entering the teaching profession despite modest high school academic grades. Perhaps for this reason neither average BMI values (24.4 kg/m² in the men, 25.3 kg/m² in women) nor average skin-fold estimates of body fat percentage (18.0% in men, 26.5% in the women) were particularly remarkable relative to the general student population. Wasiluk et al. (2013) also found few inter-faculty differences in body fat content among 165 first-year Polish university students who were enrolled in courses in physical education, physiotherapy, tourism and sport, and cosmetics. Likewise, Bale (1980) reported relatively high skin-fold estimates of body fat (average 24%) in 53 English female physical education students.

Several reports made direct comparisons of body fat between physical education students and their peers who had enrolled in other faculties. Four such investigations found lower fat levels among the physical education students of both sexes (Arazi et al, 2011, 2012; Lutoslawska et al., 2014; Reuter et al., 2012), and another found low fat levels in the males only (Neculăes & Lucaci, 2016). However, one report that considered only female students found no lower fat levels in the physical education group than in students from other disciplines (Wasiluk et al., 2013).

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Table 3: Estimates of percentage body fat for physical education students and their peers in other faculties.				
Author	Sample	Body fat		Comments
		Male	Female	
Arazi et al. (2011)	140 female "athletes" and 160 "non-athletes"		BMI 20.5 vs. 25.2 kg/m ²	Iran
Arazi et al. (2012)	160 male POE students, 170 other faculties	BMI 21.9 vs. 27.3kg/m ²		Iran
Bale (Bale, 1980)	53 Female phys. ed. students		24.0%	
Kvintová & Sigmund (2016)	114 active, 243 inactive female university students		20.9 (active) 27.8 (inactive)	"Active" criterion 150 min/wk at 3-6 METS or 75 min/wk at 6 METS
Lutoslawska et al. (2014)	90 M, 87 F phys. ed. (pe) students, 49 M, 46 F from other faculties (o)	14.4 (pe) 16.7 (o)	25.2 (pe) 30.9 (o)	Poland; PE students physically active 7-9 h/week
Meckel et al. (2011)	85 M, 89 F physical education students at entry (e) and end of freshman year (f),	13.2 (e) 14.0 (f)	25.8 (e) 26.6 (f)	Israel. Increase of fat paralleled by slowing of 2 km run; loss of fitness most marked in those initially fittest
Morinaka et al. (2012)	22 Japanese, 27 Thai university students		23.0 (Japanese) 26.7 (Thai)	
Neculăes & Lucaci (2016)	PE, Kinesiotherapy, Fitness, Sports (127 F, 167 M students)	10.9 (PE) 12.7 (K) 13.8 (F) 13.1 (S)	21.5 (PE) 20.5 (K) 19.3 (F) 20.7 (S)	Romania
Pribis et al. (2010)	5101 US university students, 1996 to 2008	11.6	22.4	Body fat increased 0.51%/yr in men and 0.65%/yr in women
Reuter et al. (2012)	Phys. ed. (15 M, 27 F) and med. (18 M, 25 F) students	16.7 (pe) 21.6 (med)	28.3 (pe) 31.1 (med)	Brazil
Shephard and Pimm (1975)	Non-smoking physical education students (68 M, 74 F)	18.0	28.5	Toronto
Smolarczyk et al. (2012)	161 men, 74 women physical education students	12.5	21.5	Poland; body fat > 25% in a third of women students
Stachoń & Pietraszewska (2013)	252 male phys. ed. students	19.6 (va) 21.9 (ma)		Students classed as vigorously (va) or moderately (ma) active
Tarnus & Bourdon (2006)	14/23 male, 22/43 female "sportive" students	22.1 (sportive) 24.3 (non-sportive)	33.7 (sportive) 35.9 (non-sportive)	
Wasiluk et al. (2013)	165 first-yr students in PE, Physiotherapy (pt), Tourism (t), Cosmetics (c).		24.5 (pe) 25.0 (pt) 23.3 (t) 23.8 (c)	Poland

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Arazi et al. (2012) compared 160 male PE majors with 170 other male Iranian students, finding respective body fat estimates of 14.1% and 21.1%; there were parallel differences in body mass index (BMI) and waist-hip ratios. 140 female "student athletes" attending the same university were compared with 160 non-athletic females in terms of body mass indices (Arazi & Hoseini, 2011); again substantial differences favouring the athletic group were observed (BMI values of 21.5 vs. 25.2 kg/m², with parallel differences in waist-hip ratios).

Lutoslawska et al. (2014) compared 90 male and 87 female physical education students with 49 males and 46 females drawn from other faculties. They found somewhat lower skin-fold estimates of body fat in the PE students (many of whom were physically active for as much as 7-9 hours per week) than in their peers. Further data on Polish male physical education students (Saczuk, Wasiluk, & Wilczewski, 2016) showed a small secular trend to an increase of BMI over 25 years of observation: respective values were 23.6 kg/m² in 1989, 23.8 kg/m² in 2004, and 24.1 kg/m² in 2014.

Morinaka et al. (2012) compared findings in small groups of female Japanese and Thai students. Body fat levels were unremarkable for students from faculties other than physical education. Nevertheless, when accelerometer measures of daily activity were compared with bio-impedance measures of body fat, a substantial negative correlation ($r = -0.48$) was seen in the Japanese students. However, this was not apparent in their Thai peers, perhaps because most of the latter group engaged in very little physical activity overall.

Neculăes & Lucaci (2016) evaluated the body fat levels of 217 female and 167 male Romanian students who were enrolled in 4 different health science and fitness-oriented faculties. The body fat percentages were low, especially among the male students (10.9%-13.8%), with BMI values for the first 3 categories of student ranging from 22.9-24.4 kg/m² in the men, and 20.7 to 20.9 kg/m² in the women.

Pribis et al. (2010) reported quite low skin-fold estimates of body fat (an average of 11.6%) in a sample of male university students in Michigan who were participating in physical activity classes, but the average values for female students were higher (22.4%). Pribis et al. commented on a significant trend to an increase of body fat over the 12 years of observation, between 1996 and 2008, this had averaged 0.51%/year in the men and 0.65%/year in the women, and it was associated with a secular decrease of maximal oxygen intake in both sexes (Pribis et al., 2010). The suggested explanation was a decrease in habitual physical activity of the Michigan student population over the 12-year period. However, such large changes in body fat content could also reflect secular changes in the diet and ethnic composition of the student samples, as well as artifacts from changes in the personnel making the skin-fold measurements.

Reuter et al. (2012) compared small samples of physical education and medical school students who were attending a Brazilian university. Data on body fat, as obtained by dual-energy x-ray examination, showed a small advantage to the physical education students of both sexes (16.7% and 28.3%) relative to the medical students (21.6% and 31.3%).

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Comparisons based on objective measurements of habitual physical activity. Additional proof on the efficacy of regular physical activity as a means of preventing obesity among university students can be found in studies where individuals have been classified based upon their reported or objectively-measured level of habitual physical activity rather than on the faculty in which they were enrolled.

Thus, Kvintová & Sigmund (2016) categorized 357 female students on the basis of their reported physical activity; 114 of the group were classed as physically active (individuals spending > 150 minutes/week at an exercise intensity of 3-6 METs, or 75 minutes/week at >6 METS). This segment of the population had a substantially lower level of body fat than their sedentary peers (20.8% vs. 27.8%), with parallel differences of BMI.

Rutter (1994) studied the activity patterns of 39 female university students using a Caltrac personal activity computer. They reported correlations as high as -0.38 to -0.47 between habitual physical activity and BMI, although perhaps because of an initial reactionary response to wearing of the accelerometer, significant relationships were not seen until the accelerometer had been fitted for 4-6 days.

Tarnus & Bourdon (2006) examined a small sample of university students living on the island of La Réunion. All of this group were rather fat relative to their peers in other parts of the world, but there were nevertheless significant differences of obesity between students classed as "sportive" (those practicing exercise for 1 hour or more per week) and the "non-sportive;" respective levels of body fat were 22.1% vs. 24.3% in the men, and 33.7 vs. 35.9% in the women).

Zanovec et al. (2009) used the International Physical Activity Questionnaire to classify 142 male and 148 female Baton Rouge university students into quartiles of habitual physical activity, expressed in MET-hours of physical activity week. There was a substantial gradient of obesity between the most active quartile (23.0% body fat) and the least active (25.8% body fat), and there was also a modest inverse correlation between the physical activity scores and an assessment of body fat content made by dual energy x-ray absorptiometry ($r = -0.40$). However, the findings in this study were not co-varied for sex, and a spurious association may have been created because of a combination of the inherently greater fat content of the women and their lower average levels of physical activity. Ruchan (2015) also demonstrated a relationship between body fat levels and habitual physical activity as assessed by responses to the International Physical Activity Questionnaire.

Summary

Summarizing the reports listed in Table 3, all except 2 of the male studies showed fairly low levels of body fat, the exceptions being the studies of Stachoń & Pietraszewska (2013) and Tarnus & Bourdon (2006). In contrast, fat levels for a number of the female samples have not been much lower than would be anticipated in the general population of university age. Nevertheless, the data generally support the contention that university students who are involved in a physical education programme or some other form of regular vigorous physical activity maintain a lower percentage of body fat than those who are content with a sedentary lifestyle. Moreover, this benefit

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is apparently obtained without any deliberate restriction of dietary intake, and in some instances has been seen with participation in quite a modest volume of weekly activity.

Physically demanding vs. sedentary occupations

Early occupational epidemiology was based upon comparisons of people who were engaged in heavy versus sedentary work. Automation and robotics has now eliminated many traditional "heavy" jobs, but even today certain occupations such as emergency workers and elite military units still find periodic demands for substantial occupational energy expenditure. Where information is available, it is instructive to compare the body composition of workers in such jobs with data for those who are employed in more sedentary professions. It is also useful to look at the impact of employee fitness programmes upon the body composition of participants.

Body fat levels seen in classical occupational epidemiology

Morris & Raffle (1956) made one of the earliest occupational comparisons of body build, fitness and life expectancy, looking at differences between the drivers and conductors of London Transport double-deck buses. During the early part of the 20th century, the conductors were required to run up to the top deck of these vehicles several times every kilometer of the bus route in order to check tickets and collect fares from the passengers, whereas the drivers spent most of their day seated in the comfort of the driver's cab. The comparison of body fat content seemed a valid one, since both conductors and drivers were drawn from the same socio-economic milieu, ate in the same canteens,

and had few differences in working conditions other than their daily physical activity.

A substantial difference of waist girth was seen in company records of trouser sizes, the respective percentages of drivers and conductors having a waist measurement greater than 36 inches rising from 7.9% and 3.4% when recruited (at ages 25-29 years) to 39.7% and 22.4% at ages 45-49 years and 63.2% and 43.0% at ages 55-59 years. There was an initial difference in waist circumference of about one inch when the men were first recruited to the bus system (presumably reflecting some initial selection of sedentary vs. active work), but by the time of retirement, this difference had increased to about 2 inches. Further studies of London busmen found a corresponding 1 mm difference of average skinfold thicknesses between conductors and drivers (8 vs. 9 mm) at recruitment (Oliver, 1967).

Emergency workers

Emergency workers may on occasion be asked to perform very hard physical work, and entry standards often require a high level of physical fitness, but personnel do not necessarily show low levels of body fat even on entry to such occupations; indeed, one U.S. study (Tsismenakis et al., 2009) found that a third of recruits had an initial BMI > 30 kg/m². After recruitment, body composition may worsen, particularly if it is necessary for the worker to sit long periods waiting for an emergency to occur. This problem seems particularly prevalent in firefighters. In a sample of 115 Missouri firefighters (Poston et al., 2011), 54 were rated as over-weight, and 38 as obese (12 with class II or class III obesity). Studies of firefighters have also found body mass

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increasing by 2.6 kg over the first 5 years of employment, with the prevalence of obesity increasing from 33.7 to 40.4% (Soteriades et al., 2005), and body mass increasing by as much as 1.4 kg/year (Elliot et al., 2007). In addition to sitting for long periods in the fire-hall, firefighters face problems of adaptation to shift work, with disturbances of their diet and sleep patterns.

Even with the more sustained physical demands encountered in fighting forest fires, Budd (2001) found body fat percentages in Australian fire-fighters ranging from 7% to 27%. The focus in many of the fitness tests used when recruiting wild-land firefighters has been on aerobic fitness and muscular strength rather than body fat content, although the latter does have a marked influence upon their risk of injury and thus of absenteeism.

Employee fitness programmes

A number of companies where most jobs involve little physical effort have introduced worksite fitness programmes; these can result in a 10-30% reduction of skin-fold readings among participants (Shephard, 1996).

Military recruits.

Current evidence of an inverse

relationship between the physical demands of occupational activity and body fat content is most evident in studies of the armed forces, especially in reports concerning elite fighting groups (Table 4), where some extremely low values have been observed.

Campos et al. (2017) documented the effects of 12 weeks of basic training upon the body composition of 18-19-year-old male recruits to the regular Brazilian military. Over a period of preliminary conditioning, the average thickness of 3 skin-folds decreased from 14.1 mm to 11.2 mm, and the corresponding prediction of body fat dropped from 14.0% to 11.6%, with a parallel dramatic increase in maximal oxygen intake (from 35.2 to 49.8 ml/[kg.min]).

Farina et al. (2017) examined a group of 50 male U.S. "special forces" who engaged in 155 min of aerobic training and 180 min of strength training every week. A skin-fold based determination of body fat showed readings of 10.4% both initially and after 3-6 months of deployment.

Malavolti et al. (2008) used 3 techniques (skin-folds, air plethysmography and dual x-ray absorptiometry) to determine the body fat content in 27 male naval recruits who successfully completed 9 months of

Author	Group	Body fat	Methodology
Campos et al. (2017)	130 Brazilian military recruits, 12 wk basic training	Initial 14.0% Final 11.6% Skin-folds 14.1, 11.2 mm	Skin-fold prediction
Farina et al. (2017)	50 male U.S. Special Forces	10.4%	Skin-fold prediction
Malavolti et al. (2008)	27 male naval recruits undergoing special training	Initial 13.0%, 6 months = 11.5% skin-folds 9.4 and 8.3 mm	DXT
Nindl et al. (2007)	50 male participants, U.S. Army 4-wk Ranger Course	18.5% initial 8.8% final	DXT
Paff & Kometa (2000)	39 Polish paratroopers, 18 months training	15.0% initial 13.1% final	Skin-fold predictions

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intensive training. On average, dual x-ray estimates of body fat content fell from 13.0% to 11.5%, while the average of 6 skin-fold thicknesses decreased from 9.4 mm to 8.3 mm during the 9 months of observation.

Nindl et al. (2007) also used dual x-ray absorptiometry to demonstrate that an 8-week U.S. army ranger course with an energy expenditure of 32-40 MJ/day, and an energy deficit of ~4 MJ/day decreased body fat from an initial 18.5% to 8.8%.

Paff & Kometa (2000) noted a decrease of anthropometrically determined body fat in 39 presumably male Polish paratroopers over 18 months of training, with values falling from 15.0% at recruitment to 13.1% after 18 months of military service. Anaerobic capacity and muscle strength also increased, but there was no change of maximal oxygen intake.

Traditional Amish and Mennonite groups vs. sedentary North Americans

The Amish people have their historic roots in Swiss German Anabaptist churches. They are a community known particularly for their plain dress and simple lifestyle. Many of the old-order Amish believers migrated to North America in the early 1700s; currently, there are some 200,000 living in the eastern part of the U.S. and around 1600 in southern Ontario. Old-order Mennonites are a related sect, originating in Switzerland and southern Germany; they also, have retained a plain lifestyle. The traditional Amish and a segment of Old-order Mennonites use no modern power tools or modern vehicles on their farms, and in consequence their daily routine requires very high daily energy expenditures (Table 5). Their children, likewise, are allowed no mechanical or electronic devices, they are expected to

help around the farm, and they usually walk a substantial distance to school, so that they also incur very high daily energy expenditures.

Adult Amish and Old-order Mennonites

The impact of the simple and traditional, non-mechanized lifestyle upon habitual physical activity can be seen in daily step counts for the Amish and Old-order Mennonite populations.

Bassett et al. (2004) examined 98 U.S. Amish adults aged 18-75 years who still engaged in labour-intensive and non-mechanized farming, finding daily pedometer step counts averaging 18,425 for the men and 14,196 for the women. Moreover, use of the International Physical Activity Questionnaire suggested that vigorous physical activity was undertaken for 10 h/week by the men and 3.4 hours/week by the women. On the basis of BMI (a somewhat fallacious index in a group performing much heavy muscular work), only 25% of men and 27% of women were classed as overweight, and none of the men and only 9% of the women were classed as obese. Bio-impedance data indicated body fat values of 9.4% in the men and 25.3% in the women.

Glick et al. (1998) compared traditional Old-order Mennonites (87 men and 72 women) with the general U.S. population as both groups were examined in the 1987 NHANES survey. The Mennonite men and women both had a somewhat lower self-reported BMI than

that seen in the general U.S. population, despite a larger food intake among the Mennonites (20% greater in the men, and 39% greater in the women). Moreover, because the Mennonites used their muscles extensively to undertake physical tasks, the difference of body fat content

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Table 5: Habitual physical activity and measures of obesity in traditional Amish and Mennonite populations.

Author	Sample	Habitual physical activity	Measure of obesity	Comments
Bassett et al. (2004)	98 Amish adults, aged 18-75 yr	Daily step count 18,425 (M), 14,196 (F)	Overweight 25% (M), 27% (F), obese 0% (M), 9% (F) Impedance fat 9.4% (M), 25.3% (F)	Vigorous PA 10 h/wk (M), 3.4 h/wk (F)
Bassett et al. (2007)	139 Amish youth aged 6-18 yr	Weekday step count 17,525	Only 7.2% overweight, 1.4% obese	
Esliger et al. (2010)	68 Amish, 120 Mennonite, 132 rural & 93 urban contemporary children aged 8-13 yr	Actigraph data show less moderate & vigorous activity in contemporary children than in Amish & Mennonite	BMI 17.2 vs. 19.8 vs. 19.0, 18.8 kg/m ² ; Triceps skin-fold 10.6 vs. 16.5, vs. 17.7, 18.0 mm.	
Fuchs et al. (1990)	400 Amish adults, 773 controls		No difference of obesity in men (28%), Amish women more obese than controls (40% vs. 31%)	Amish no longer pursuing traditional agriculture
Glick et al. (1998)	80 M, 69 F Old-order Mennonite, vs. 12,275 M, 14,815 F US NHANES population		BMI 24.8, 24.7 in Mennonites, vs. 26 kg/m ² in M & F NHANES sample	Old-order Mennonites vs. 1987 NHANES survey
Tremblay et al. (2008)	127 Mennonite, 275 contemporary children aged 8-13 yr	Moderate & vigorous physical activity: Mennonite 12 (urban) or 18 (rural) more min/day than peers	Skin-fold thicknesses greater in both urban and rural contemporary children than in Mennonites	Mennonite children also had greater aerobic fitness and strength than their peers

from sedentary individuals was probably substantially greater than that inferred from the BMI data.

In contrast to the low body fat levels seen in these two reports, Fuchs et al. (1990) examined 400 Amish, many of whom had moved from their farms to small towns in Ohio. Comparing the self-reported BMI of this group with that of 773 controls, they found no inter-group difference in the prevalence of obesity among the men and higher levels of obesity in the Amish women than in the controls. Precise measurements of physical activity were not obtained for this

population, but the data suggested that protection against the accumulation of body fat was not an inherited characteristic; the advantage of the Amish soon being lost when they ceased their involvement in the heavy physical labour of traditional agriculture. A third of the men studied by Fuchs and associates worked in small local industries, and many of the remainder of their sample worked as labourers on non-Amish farms, although about two thirds of the women were still full-time home-makers. Among factors contributing to the shift in body composition, Fuchs et al. (1990) noted

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that food was usually still very plentiful in the urban Amish households, and everything tended to be eaten from over-filled plates to avoid any sinful waste of food.

Most Amish still complete only a limited amount of formal education (nearly 80% of the Fuchs sample had not even completed Grade 8), so there is still a dearth of Amish professionals such as physicians, and the Amish are often reluctant to seek health advice from those living outside of their religious community. In the U.S., reluctance to visit a physician is reinforced by a low monetary income and a lack of health insurance. Further, the Amish seem less likely than their peers to engage in voluntary leisure activity if they find that they are gaining weight (Levinson et al., 1989). Some 17% of the Amish studied by Fuchs et al. were following exercise programmes, as compared with 37% of their peers. The Amish women also experienced a higher average number of pregnancies than their peers in the general Ohio population. Finally, since obesity was less stigmatized among the Amish than in the rest of U.S. society, more of them may have been willing to report high body weights than their peers.

Children of traditional Amish and Mennonite communities

Traditional Amish and Mennonite children have a much higher level of daily physical activity than their North American peers, in part because they help with chores around the farm, and in part because they do not occupy their leisure time by playing sedentary electronic games.

Tremblay et al. (2005; 2008) compared 58 Amish and 106 Mennonite children (the latter drawn from a group that used

some electrical equipment on their farms) with 267 contemporary Canadian children aged 8-13 years. The level of moderate and vigorous physical activity was much higher in the Amish and Mennonite youth than in the other Canadians. Thus, the Mennonite boys engaged in 3 h/day of vigorous physical activity, and the Mennonite girls were vigorously active 2 h/day (Tremblay et al., 2005). The Mennonite boys helped extensively with farm chores, while the Mennonite girls spent much of their evenings sewing and cooking. The Mennonite youth showed correspondingly lower skin-fold readings and higher levels of aerobic fitness and muscular strength than their contemporary peers. Triceps skin-fold values, as estimated from the published graphs, were around 11.5 and 12.5 mm for the Amish boys and girls, respectively, 15 and 17 mm for the Mennonite boys and girls and 16 and 19.5 mm for male and female controls.

Bassett et al. (2007) measured the step count in 139 Amish youth aged 6-18 years, finding a very high average weekday count (17,525 steps/day). Values for weekends were with somewhat lower, in part because of time spent sitting in church on Sundays; the 7-day average was thus 15,563 steps/day. Skin-folds were not measured in this sample, but measured height and weight data indicated that only 7.2% of this group would be classed as overweight and 1.4% as obese.

Esliger et al. (2010) compared Amish, Mennonite (not strict Old-order) and contemporary Canadian children, the latter being drawn from both urban and rural settings. Accelerometer data showed that the Amish children (and to a lesser extent the Mennonite children) engaged in more moderate and vigorous physical activity than their contemporary peers.

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There were parallel differences in the average BMI for the 4 groups (Amish 7.2 kg/m², Mennonites 19.8 kg/m², rural controls 19.0 kg/m², and urban controls 18.8 kg/m², with much larger inter-group differences in triceps skin-fold thicknesses (respective values of 10.6, 16.5, 17.7 and 18.0 mm).

Age (yr)	BMI (kg/m ²)		Triceps skin-fold(mm)	
	Men	Women	Men	Women
20-29	24.4	23.2	5t.5	8.5
30-39	24.9	23.9	6.3	9.2
40-49	25.3	23.7	5.4	7.0
50-59	25.8	27.5	7.9	19.0

Unacculturated Inuit

Another group who had very high energy expenditures when they were first studied (around the year 1970) were unacculturated Inuit living on Canada's Arctic coast. Many of this population then followed a traditional hunter-gatherer lifestyle. Measurements made by a combination of Kofrany-Michaelis respirometer and time-and-motion analyses suggested an average daily energy expenditure of 15.4 MJ during hunting trips (Shephard & Rode, 1996). This total was accumulated mainly through very prolonged bouts of moderately heavy endurance exercise. In

the summer months, if the weather was favourable for hunting, physical activity would continue over much of a 24-hour period.

Those following this lifestyle showed correspondingly low indices of body fat content (Table 6). The body mass indices were not remarkable, in part because the population was muscular, and also

because of a short stature. However, the average thickness of the triceps skin-folds was remarkably low, especially in the male members of the community. There also seemed evidence for the development of obesity in the oldest group of women, most of whom had undergone multiple pregnancies. Comparisons of body fat content with the urban Canadian population must however be made with care. Not only were the Inuit much more active physically, but they were also obtaining a large proportion of their daily food from their hunting activities.

Percentages of body fat in the Inuit sample were determined not only by skin-fold measurements, but also by the dilution of deuterated water (Table 7). The latter methodology requires making assumptions about tissue hydration, which may differ between the Inuit and urban Canadians. Certainly, the estimates of body fat content made by this method

Table 7: Percentage of body fat in Igloolik Inuit in the year 1970, as determined by the dilution of deuterated water (Mertens et al., 1996).

Age group (yr)	Body fat (%)	
	Men	Women
15-19	12.8	18.4
20-29	15.3	20.8
30-39	11.9	25.4
40-49	-	26.1

(which reflects total, rather than superficial fat) were somewhat higher than those obtained from skin-fold predictions. Possibly, the Inuit store a greater than normal proportion of their body fat internally. Nevertheless, a low total body fat content was confirmed for the males at all ages. Values for the women were also lower than would be expected in sedentary urban city-dwellers, although

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there was apparently some accumulation of fat as the Inuit women became older.

Low levels of skin-fold thickness are also apparent in data for indigenous circumpolar children from this era, whether measured at Igloolik in the Canadian arctic, or on nGnassan children living in the Russian arctic (Shephard & Rode, 1996) (Table 8).

Physically active vs. sedentary urban populations

Coefficients of correlation between estimates of body fat content and habitual physical activity have been examined frequently in modern urban populations, often in the context of evaluating the reliability and validity of physical activity questionnaires. The findings are of particular interest in the context of public health, as (unlike groups such as marathoners and hunter-gatherers), the activities involved are at an intensity and volume that are likely to prove acceptable to many current urban populations. Only a few of the many available studies can be discussed here. Many of these investigations are based on questionnaire estimates of habitual physical activity, but some have also focused on objective measurements obtained by pedometer or accelerometer.

Subjective data

In general, self-reported habitual physical activity and body fat have shown modest negative inter-correlations (Table

9), although because of errors inherent in the questionnaire approach to the assessment of physical activity, associations have necessarily been attenuated relative to their true values. For the best designs of questionnaire, and in samples with substantial differences of physical activity between those classed as active and sedentary, correlations have been as high as -0.40, but in other studies where few of the sample have engaged in any significant physical activity, much lower correlation coefficients have been reported. Correlations have generally been larger for reports of vigorous activity than for moderate or light physical activity, probably because engagement in vigorous activity is clearly perceived by the individual, and is reported more precisely. Differences of body fat content between the most active and the least active groups of individuals have been in the range 3-4%.

Ball et al. (2001) studied 1302 Australians aged 18-78 years, looking at relationships between leisure activity, BMI and an estimate of body fat based on the average of 6 skin-folds. They noted that the odds of finding a BMI within the normal range was significantly related to a high reported level of leisure activity (less so in men than in women, the respective odds ratios being 1.8 in men, and 2.6 in women, $p = 0.04, <0.01$). After controlling for age and differences of educational level, in the women, moderate or high intensity leisure activity was also

Age (yr)	Boys		Girls	
	Igloolik	nGnassan	Igloolik	nGnassan
11.0-12.9	7.9	6.7	11.7	8.0
13.0-14.9	9.0	3.1	11.6	10.2
15.0-16.9	7.9	6.1	18.2	11.2
17.0-18.9	9.6	6.4	16.8	12.7

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Table 9: Relationship between self-reported habitual physical activity and body fat content.				
Author	Sample	Fat measure	Correlation with body fat or other measure	Comments
Ball et al. (2001)	1302 M & F aged 18-78 yr	BMI and 6 skin-folds	Odds of normal BMI if high leisure activity 1.76 (M), 2.59 (F) (p = 0.04, <0.01)	Adjusted for age & education; no effect of occupation or domestic physical activity
Bouchard et al. (1983)	150 children, 150 adults	Skin-fold estimate of body fat	-0.08 to - 0.13	
Bradbury et al. (2017)	119,230 M, 140,578 F	BMI, Bio-impedance estimate of body fat	Body fat 23.4% vs. 26.3% M, 33.9% vs. 37.9% F).	Most active (>100 MET-h/wk vs. least active (<5 MET-h/wk)
Ekelund et al. (2005)	17-yr old students (190 M, 255 F)	Air-displacement plethysmography	-0.18 (M) -0.03 (F)	All activity levels low in F students
Folsom et al. (1985)	3448 Minnesota adults aged 25-74 years	BMI	-0.10 (F) to - 0.11 (M) with Log of reported heavy activities per day	Activity levels generally low in this population
Godin & Shephard (1985)	163 men and 143 women	Skin-fold estimate of body fat	- 0.21	Significant r for strenuous but not for moderate or light physical activity
Jacobs et al. (1993)	78 men and women aged 20-59 yr	Hydrostatic measures of body fat	-0.37 to - 0.44 for best questionnaires, 0.52 for accelerometer	Comparison of 10 questionnaires
Martinez et al. (1999)	15,239 M & F aged > 15 yr	Self-reported BMI	Low exercise participation (p<0.0001), lack of interest in PA, sitting at work (p = 0.0004) all predictors of obesity	
Richardson et al. (1995)	78 men and women aged 20-59 years	Hydrostatic estimate of body fat %	-0.37 in men, -0.44 in women	Correlation seen for sport and deliberate exercise, less apparent for non-sport light physical activity
Wanner et al. (2016)	1440 M, 1602 F	Bio-impedance estimate of body fat, BMI, waist measurements	OR total physical activity 0.60 Moderate phys. activity 0.67 Vigorous phys. activity 0.59 Sitting 1.59	Odds ratio for >32% fat, high vs. low level of activity
Washburn et al. (1991)	306 M, 417 F, average age 39.5 years Boston population	Log BMI	-0.13 (-0.11 M; - 0.17 F); overall value of -0.41 after co-variate adjustment	BMI for most active tertile 25.1, least active 26.7 kg/m ²

associated with a low body fat content.

However, the BMI and skin-fold readings were unrelated to estimates of

occupational or domestic physical activity in either sex.

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Bouchard et al. (1983) used a 3-day diary record to estimate habitual physical activity in a group of 150 children and 150 adults who were participating in the Quebec family study. They noted quite low negative correlations between skin-fold assessments of body fat content and the diary records of physical activity (-0.08 to -0.13).

Bradbury et al. (2017) stratified a very large sample of English adults (119,230 men and 140,578 women participating in the U.K. Biobank 2006-2010) in terms of their bio-impedance estimates of body fat content. The results showed that individuals reporting the most physical activity on the International Physical

Activity Questionnaire (100 MET-h/week) had consistently lower body fat content than the least active members of the same sample (<5 MET-h/week) (23.4% vs. 26.3% in men, 33.9% vs. 37.9% in women). The measured BMI values were also lower for the active group (27.1 vs. 28.0 kg/m² in the men, 25.7 vs. 27.2 kg/m² in the women).

Folsom et al. (1985) examined a representative sample of Minnesota residents aged 25-74 years. Levels of physical activity in this sample were generally low, but nevertheless small negative correlations were shown between the log of reported leisure-time physical activity (kCal/day) and body mass index, both in men (-0.11) and in women (-0.10). Leisure activity was associated with a good education and a type A personality, but the authors did not adjust for these factors by a multivariate analysis.

Godin & Shephard (1985) sought data to validate their simple physical activity questionnaire in a sample of 163 men and 143 women recruited from the University of Toronto community. Correlations with a

four site skin-fold assessment of body fat were substantial and highly significant for reports of strenuous leisure physical activity (activity at an estimated intensity of 9 METs, $r = -0.21$), but were smaller and not statistically significant for reports of moderate (6 METs) or light (3 METs) intensity physical activity.

Jacobs et al. (1993) involved 78 men and women aged 20-59 years in a simultaneous assessment of 10 different physical activity questionnaires, using accelerometer measurements as their criterion data. Hydrostatic estimates of body fat showed correlations ranging from -0.37 to -0.44 with what were judged as the best of the 10 questionnaires, and 0.52 with the accelerometer data.

Martinez et al. (1999) examined the self-reported BMI of 15,239 Europeans aged >15 years. About 10% of the group was obese on this criterion, and the prevalence of overweight was 35.6% and 25.6% in men and women respectively. A low participation in various leisure-time physical activities, a lack of interest (a lack of pre-contemplation) in being involved in exercise/physical activity and an increasing number of hours sitting down at work were all predictors of obesity.

Richardson et al. (1995) used the Baecke questionnaire and an accelerometer to assess physical activity patterns in 78 adults aged 20-59 years. A hydrostatic estimate of the percentage of body fat showed a relatively strong negative relationship ($r = -0.37$ in men, -0.44 in women) with participation in sport and deliberate exercise, but less substantial relationships were found for other forms of light activity (-0.09 in men, -0.51 in women). Unfortunately, the associations between body fat and accelerometer data were not reported in this study.

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Wanner et al. (2016) estimated body fat levels in a sample of Swiss adults (1440 males and 1602 females), using the bio-impedance technique. Relationships with habitual physical activity as assessed by the International Questionnaire of Physical Activity were evaluated in terms of the odds of developing >32% body fat. On comparing the highest versus the lowest tertiles, the odds of accumulating >32% fat were reduced by total physical activity (0.60), moderate intensity physical activity (0.67) and vigorous physical activity (0.59), and were increased with sitting time (1.59). Similar relationships were shown for BMI, waist circumference, and the weight-to-height ratio.

Washburn et al. (1991) sought to validate general use of the Harvard Alumni Physical Activity Questionnaire. They examined 306 men and 417 women from the Boston area with an average age of 39.5 years. Activity levels were separated into 3 categories, as proposed by Paffenbarger (<2MJ/week, 2-8 MJ/week and >8 MJ/week). In the men, the sample was divided rather equally between the 3 activity categories, but 39% of the women expended <2 MJ/week on physical activity. The study showed a modest unadjusted correlation between the questionnaire assessment of habitual physical activity and the log of BMI (-0.11 in men, -0.17 in women), but the correlation coefficient for the entire sample was increased to -0.41 when data were adjusted for significant co-variables that included ethnic group, cigarette smoking and the mean monthly temperature at the time of the interview.

Ekelund et al. (2005) examined correlations in a somewhat younger age group, looking at the relationship between body composition as assessed by an air-

displacement plethysmograph and a questionnaire estimate of physical activity in Swedish children aged ~17 years. A significant negative relationship between the 2 variables was found in the boys ($r = -0.18$), but not in the girls ($r = -0.03$), who in most cases had very low average levels of habitual physical activity. The difference in exercise behaviour was reflected in the average body fat levels for boys and girls (16.3% vs. 29.3%).

Objectively monitored physical activity

Estimates of habitual physical activity as determined by pedometer, accelerometer or Sense-Wear arm band are generally more accurate than those inferred from responses to questionnaires, although there remain some forms of physical activity such as climbing a hill, cycling and swimming that are still not assessed accurately by a pedometer or accelerometer. Probably because of the greater precision of the objective measurements, correlations with the body mass index or the estimated percentage of body fat are usually greater for the objective than for the subjective data, with correlation coefficients sometimes reaching 0.50 or higher (Table 10). However, the apparent magnitude of associations has unfortunately been exaggerated in some studies, because the investigators have failed to separate data for male and female subjects; the men have tended to be both more active and thinner than the women.

In a study of 78 men and women aged 20-59 years, Jacobs et al. (1993) found an age and sex adjusted correlation of 0.52 between body fat as determined by hydrostatic weighing and Caltrac accelerometer data expressed in kCal/day, although the correlation decreased to -

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Table 10: Relationships seen between objectively measured habitual physical activity and body mass index or body fat content.

Author	Sample	Fat measurement	Correlation	Comments
Jacobs et al. (1993)	78 men and women aged 20-59 yr	Body fat by hydrostatic weighing	-0.52 (age and sex adjusted kCal/d), -0.08 MET-min/d)	
Lohman et al. (2008)	1440 eighth-grade schoolgirls	Skin-fold measures of body fat	-0.12 (mv) -0.15 (v)	Correlations for moderately vigorous (mv) and vigorous (v) physical activity
McClung et al. (2000)	209 orthopedic patients	BMI	- 0.05	BMI for high phys. activity (8237 steps/d) 25.4 kg/m ² , low phys. activity (<3704 steps/d) 27.4 kg/m ²
Rowlands et al. (1999)	34 children aged 8-10 yr	Skin-fold measures of body fat	-0.42	
Scheers et al. (2013)	370 middle-aged adults	Waist circumference	-0.61 partial correlation coefficient	Sense-wear arm band data; odds ratio for abdominal obesity in active individuals 0.15
Tryon et al. (1992)	127 women aged 19 to 55 years	BMI	-0.22	
Tudor-Locke et al. (2001)	109 men & women, average age 45 yr	Impedance estimate of body fat	-0.27; similar correlation with BMI (-0.21)	Body fat 26.2% most active tertile, 32.3% least active tertile (but not co-varied for sex)

0.08 if the Caltrac output was expressed as MET-min/day).

McClung et al. (2000) examined 201 patients who were undergoing surgical treatment for orthopedic disorders. In this sample, there was only a very weak correlation between BMI and pedometer estimates of daily step count ($r = 0.05$). Nevertheless, the patients with the highest activity levels in this sample (>8237 steps/day) had an average BMI of 25.4 kg/m², compared with 27.4 kg/m² for those with very low levels of daily physical activity (<3704 steps/day).

Scheers et al. (2013) used a Sense-Wear arm-band to define physical activity patterns in 370 middle-aged Flemish adults. Abdominal obesity, as indicated by waist circumferences, showed a strong negative partial correlation (0.61) with

habitual physical activity as indicated by the arm-band output. The odds ratio of showing abdominal obesity in the most active group (active > 60 min/day) was a dramatic 0.15, relative to those in the least active group (active <30 min/day).

Tryon et al. (1992) related body mass index to a pedometer measurement (distance traveled per hour) in 127 women ranging from 14% underweight to 99% overweight; they found a small negative correlation between the 2 data sets ($r = -0.22$).

Tudor-Locke et al. (2001) assessed the relationship between pedometer step counts and body fat content in a sample of 109 older men and women (average age 45 years). The percentage body fat increased from 26.2% in the most active

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Table 11: Average aerobic fitness and skin-fold thickness found in Igloolik men in 1970. Comparison of traditional hunters, their acculturated peers, and an intermediate group in the course of making transition to a sedentary lifestyle. Based on the data of Rode and Shephard (1973).

Current Lifestyle	Maximal oxygen intake [mL/(kg.min)]		Average skin-fold thickness (mm)	
	Summer	Winter	Summer	Winter
Traditional hunters (n = 20)	56.6	56.2	5.8	6.4
Transitional (n = 22)	54.9	54.9	6.1	6.7
Acculturated (n = 18)	51.1	50.1	6.7	7.9

tertile (>9357 steps/day) to 32.3% in the least active tertile (< 5267 step/day), although this comparison was somewhat confounded because there was a greater percentage of women in the least active tertile.

Associations between habitual physical activity and fatness have also been demonstrated in children. Lohman et al. (2008) related skin-fold estimates of body fatness to accelerometer measures of habitual physical activity in 1440 eighth-grade U.S. schoolgirls, finding slightly stronger negative correlations for vigorous (-0.15) than for moderately vigorous (-0.12) physical activity.

Rowlands et al. (1999) also found negative correlations between skin-fold assessments of body fat and accelerometer data in 8-12-year old children; however, correlations as high as $r = -0.42$ must unfortunately be discounted, because data were not separated by sex, despite substantial differences in physical activity levels between the boys and the girls.

Unacculturated vs. sedentary/inactive circumpolar residents

Various cross-sectional comparisons can be drawn between circumpolar residents who have conserved a very active hunter-gatherer lifestyle, and those who have adopted a more sedentary, inactive, and westernized pattern of living.

Although higher levels of body fat content can be linked to the adoption of sedentary living, it is important to note that westernization has also brought changes in diet and other aspects of personal lifestyle to the more acculturated segments of the circumpolar populations.

Comparisons of body fat within the Igloolik population

During the 1970s, Inuit living in the Canadian arctic moved to small coastal settlements constructed by the Canadian government around schools and nursing stations. One such recently built but still isolated hamlet was Igloolik, near the tip of the Melville Peninsula. At this time, it was possible to distinguish 3 groups of men within the community - those who continued living off the land, pursuing their traditional hunter-gatherer economy, those who had become acculturated to a sedentary and inactive western lifestyle, and an intermediate group, in the course of making a transition between the two ways of life (Table 11). Differences in habitual physical activity between the three groups can be inferred from the gradation of directly measured maximal oxygen intakes between the three groups. Although the change in lifestyle was of fairly recent date, there were already differences in the thickness of skin-folds, both during the summer and the winter months. During the darkest

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accumulation of fat in previously thin populations with transition to a sedentary lifestyle argues against a genetic explanation of the associations noted in this article, and in some of the comparisons (such as those between university faculties), there is also no strong reason to suppose dietary differences between thin and fatter individuals.

The association between high energy expenditures and low levels of body fat is particularly obvious in endurance athletes, but nevertheless there are examples of other less highly selected and only moderately fit individuals who have undertaken 100 or more days of marathon-style exercise, thereby reducing their body fat content by 6-8 kg or more.

In the case of physical education students, the impact of their educational choice upon body fat content is more evident in male than in female students. In some schools, complications of interpretation have arisen from terms assigned to academic rather than physical education instruction, and not all PE students have had a strong commitment to their physical development. Inferences would be clarified by further studies using objective methods to measure the amount of weekly physical activity actually undertaken by individual students, and also by exploring the extent of involvement of supposed control students in physically demanding inter-collegiate sports programmes.

Early occupational studies often focused on cardiac risk factors other than fat accumulation, but comparisons of waist circumferences between conductors and bus drivers showed a significant advantage to the conductors, despite similarities in socio-economic status and lifestyle between the two classes of

employee. Today, there is only a limited possibility of making further occupational comparisons; bus drivers rather than conductors now collect fares from passengers, and many jobs that formerly required hard physical work have been eliminated by automation and robotics. However, heavy physical demands are still made on elite military groups, and available reports document that such troops consistently have very low levels of body fat.

The high levels of physical activity found in traditional Amish and Old-order Mennonite families are reflected in correspondingly low levels of body fat, and the changes of body composition in Amish who have abandoned their traditional rural life to work at more sedentary jobs within Ohio towns provides evidence that their traditional thinness is a consequence of a heavy daily energy expenditure rather than a genetic trait or some other facet of their personal lifestyle. Nevertheless, communal meals appear to play an important role in traditional Amish families, and it would be useful to obtain confirmatory data on the nature and extent of their daily food intake.

Cross-sectional studies of the general population seeking to validate both physical activity questionnaires and accelerometers have shown correlation coefficients as high as -0.50 with estimates of body fat content. Correlations have been largest for the best of the questionnaires, and have also been greater for reports of vigorous than for moderate or light activity,

Inuit who have maintained a hunter-gatherer lifestyle are another group with very low levels of body fat. Here, there remains scope for further study of fat distribution between superficial and deep

body depots, and to examine whether the tendency to internal fat storage is important in maintaining thermal balance when undertaking heavy physical work. It also remains interesting to clarify why the oldest Inuit females carry substantial amounts of fat; is this a consequence of multiple pregnancies, or are there substantial sex-based differences in activity patterns within the household?

Although the various comparisons discussed in this article point strongly to the efficacy of vigorous physical activity in containing the accumulation of body fat, it may be asked whether the amounts of activity needed are realistic for the general middle-aged population. The average person is certainly not going to engage in a cross-Canada run, or even to run in a marathon event, and in many of the comparisons we have cited the physically active group is undertaking much more than the minimum public health recommendation for daily physical activity. However, the minimum volume needed to prevent obesity is probably in the range of 150-250 minutes of moderate to vigorous aerobic activity per week, and this target seems well within the capacity of the average middle-aged adult. The challenge to the public health professional is to maintain enthusiasm for this attainable goal.

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