Physical activity and health

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Summary

Physical activity levels in the UK are low. Only 35% of men and 24% of women reach the recommended 30 minutes of moderate-intensity physical activity at least five times a week. Men tend to be more active than women at all ages, and there is a marked decline in physical activity with age in both sexes. Children are more active than adults. Seventy per cent of boys and 61% of girls reach the recommended 60 minutes of moderate-intensity physical activity a day. Boys tend to be more active than girls and there is a decline in physical activity as children reach adolescence, which is more marked in girls. For adults and children, lower-income groups have particularly low physical activity levels. Although physical activity levels in adults and children have been relatively stable in recent years, there is some evidence to suggest a decline in occupational activity from the 1990s onwards, and a decrease in active transport to school and time spent in school physical education lessons. This has coincided with an upward trend in sports participation (*e.g.* joining fitness clubs) in adults.

The physiological effects of physical activity are wide ranging, and affect various body systems. As a modifiable component of energy expenditure, physical activity can affect energy balance. However, the total effects of physical activity on total energy expenditure go beyond the physical activity-induced energy expenditure. Increases in resting metabolic rate and non-exercise activity thermogenesis are also seen. Furthermore, physical activity can modify body composition favourably by decreasing fat mass and increasing lean mass.

Physical activity can reduce resting blood pressure and increase capacity to carry blood in the coronary arteries. Beneficial changes also occur in the lining of blood vessels which help direct the appropriate distribution of blood in the body. Regular physical activity can also exert beneficial effects on the body's capacity for forming and breaking down blood clots, and produces favourable changes in plasma lipid profile. Physical activity is known to improve blood glucose handling and is also associated with beneficial immunological (with the exception of intense activities of long duration) and neurological changes.

In terms of its interaction with food intake, physical activity tends not to lead to an increase in energy intake in the short-term. But long-term studies indicate that negative energy balance cannot continue indefinitely; eventually energy intake increases until energy balance is resumed. In those who are physically active, the greater energy intake needed to match energy expenditure means that it is easier to achieve adequate micronutrient intakes. In addition, those who are more active adapt to using fat as an energy substrate more effectively.

Physical activity is commonly assessed using self-reported (subjective) measures such as diaries, physical activity logs, recall surveys and questionnaires, and these methods have been relied upon heavily in epidemiological studies and surveys conducted to date. Unfortunately, self-reported measures of physical activity are limited in terms of reliability and reliance on accurate recall from participants in studies. This hinders research in this area because measurement error is likely to possibly underestimate the strength of observed relationships between physical activity and health, and weaken the effects of physical activity interventions.

Despite these measurement issues, there is substantial evidence that physical activity is protective for a number of chronic diseases, both independently and via its effects on weight gain and obesity. Greater physical activity is associated with less weight gain. Weight loss programmes that include a regular physical activity component are more effective at maintaining weight loss. It is likely that for many people, 45–60 minutes of moderate-intensity physical activity a day is necessary to prevent obesity.

Physical activity (independently) reduces the risk of type 2 diabetes by 33–50%. Those who are at high risk of type 2 diabetes (*e.g.* the obese and those with impaired glucose tolerance) can benefit most from physical activity.

Physical activity reduces the risk of cardiovascular disease in a dose-dependent manner. Benefits are seen with regular moderate-intensity physical activity, *e.g.* walking, but more intense exercise, *e.g.* running, carried out more often and for longer episodes can decrease risk even further.

Physical activity has been shown to reduce the risk of a number of cancers. It is well established that physical activity reduces the risk of colon cancer (especially in men) and breast cancer (especially in post-menopausal women). There is also consistent evidence that physical activity reduces the risk of lung and endometrial cancers and some indication that physical activity can reduce the risk of advanced prostate cancer.

In childhood, physical activity habits, particularly during growth periods including puberty, have a long-lasting effect on bone health. Weight-bearing and high impact activities, such as running or skipping, are most effective at increasing bone strength. In older adults, physical activity is important to counteract the age-related decrease in bone mass. Physical activity can decrease the risk of osteoporotic fractures in older people, particularly if the activity increases muscle strength, balance and co-ordination.

There is good evidence that physical inactivity increases the risk of clinical depression. There is also good evidence that physical activity has an important beneficial effect on anxiety. Furthermore, physical activity is important for psychological wellbeing and can be used as a means to improve mood and self-esteem.

It is clear that physical activity exerts its benefits throughout the life course. In childhood, physical activity is important as a means of maintaining energy balance and helping bone strength, and thus reduces the risk of chronic disease later in life. It is also important for social interaction, wellbeing and setting good lifestyle habits. It is recommended that children and young people achieve a total of at least 60 minutes of at least moderate-intensity physical activity each day. At least twice a week this should include activities to improve bone health (*e.g.* skipping, running), muscle strength and flexibility.

It is recommended that adults should achieve a total of at least 30 minutes of at least moderate-intensity physical activity each day, on five or more days a week. This level of physical activity should be maintained throughout adulthood in order to reduce the risk of chronic disease and should be continued into old age for as long as capabilities allow, in order to counteract the age-related losses in muscle and bone, deterioration of the cardiovascular system and to decrease the risk of osteoporotic fractures.

Widespread physical inactivity is a major public health problem and improving physical activity levels is crucial. This challenging situation is now well recognised by international and national health bodies. The World Health Organization (2004) has a global strategy on physical activity, and in England the Department of Health (2005) has a 'Choosing Activity' physical activity action plan. In the UK, the National Institute for Clinical Excellence (NICE) offers a range of guidance on the effectiveness of different methods of promoting physical activity, but current research is limited and it is hoped that ongoing work will provide more comprehensive guidance in the coming years.

There are a number of psychological barriers to physical activity, including issues related to body image, poor confidence and lack of immediate rewards. These barriers are often marked in those who are obese and need to lose weight. Most importantly, environmental factors which contribute to low levels of physical activity should to be tackled if significant changes to population level physical activity are to be achieved. For example, policies which support active transport initiatives have proved to be effective in other countries and thus have great potential in the UK.

Further research to gain a greater understanding of the psychological and environmental barriers to increasing physical activity is likely to help direct more effective campaigns to promote physical activity in the future.

1 Introduction

Physical activity has a major impact on health. Some effects are well established; as a major component of energy expenditure, physical activity has a great influence on energy balance and body composition. It is also recognised that physical activity is a major independent modifiable risk factor which has a protective effect on cardiovascular disease (CVD), stroke, type 2 diabetes, colon and breast cancers, and is also associated with other important health outcomes such as mental health, injuries and falls.

Physical inactivity remains a public health problem in many areas of the world, including the UK. Activity levels are low in the UK; about two-thirds of men and three quarters of women do not meet the national recommendations for physical activity. This problem coexists with the rising tide of obesity. In England, obesity levels have increased from 13.2% in 1993 to 23.1% in 2005 in men, and from 16.4% to 24.8% in women over the same time period (The Information Centre, Lifestyle Statistics 2006). The UK is now one of the most obese nations in Europe (IASO 2007).

It is only recently that energy expenditure has not been inextricably linked to energy intake. In the past, food was less readily available and energy expenditure was needed to obtain food. But advances in technology and industrialisation now mean that there is a mismatch between food availability and the energy required to obtain food and go about our daily lives. Consequently, we now have a pandemic of obesity and associated chronic diseases such as type 2 diabetes.

This challenging situation is now well recognised by international and national health bodies. The World Health Organization (2004) has a global strategy on physical activity, and in England the Department of Health (2005) has a 'Choosing Activity' physical activity action plan. The economic burden of physical inactivity is immense and the estimated direct cost of physical inactivity to the National Health Service in the UK is £1.06 billion (Allender *et al*. 2007). The indirect costs of physical inactivity such as days lost to sickness absence and premature mortality, private healthcare costs and home care, increase these estimates further. The Department of Health (2004) estimates that the total (direct and indirect) cost

of physical inactivity in England to be £8.2 billion a year.

So improving physical activity levels (PALs) is crucial. However, the best methods to achieve this are not yet known and further research is needed to ascertain the effectiveness of initiatives already underway. A greater understanding of the psychological and environmental barriers to increasing physical activity is likely to help inform and direct campaigns to promote physical activity.

This briefing paper aims to highlight the importance of physical activity for health and to provide an effective overview by assimilating the latest evidence in this area. Issues related to defining and measuring physical activity are described first, and this is followed by an explanation of the physiological impact of physical activity. This briefing paper focuses on the role of physical activity on the prevention of disease, but also discusses the effects of physical activity in high-risk groups (*e.g.* the obese and those with impaired glucose tolerance) in various sections. The evidence linking physical activity to disease prevention is critically assessed in sections on weight gain and obesity, CVD, cancer, diabetes, osteoporosis, mental health and psychological wellbeing. The importance of physical activity across the life course is discussed and national recommendations for physical activity are presented. Finally, the challenges of public health interventions to improve PALs are considered and an assessment made of the risks associated with physical activity. This paper aspires to aid those working in public health and so focuses on the health effects of physical activity in the general population, rather than the implications of physical activity in the elite athlete.

2 Definition and measurement of physical activity

2.1 Definition and classification of physical activity

2.1.1 Physical activity and energy expenditure

Physical activity is defined as 'bodily movement that is produced by the contraction of skeletal muscle and that substantially increases energy expenditure' (US Department of Health and Human Services 1996). This term therefore includes the full range of human movement from competitive sport and exercise to hobbies or activities involved in daily living. Conversely, physical inactivity can be described as 'a state in which bodily movement is minimal and energy expenditure approximates the resting metabolic rate' (IARC 2002).

Physical activity affects total energy expenditure, which is the sum of the basal metabolic rate (the amount of energy expended while at rest in a neutrally temperate environment and in a state of fasting), the thermic effect of food (otherwise known as dietary-induced thermogenesis) and the energy expended in physical activity (Department of Health 1991).

Total energy expenditure (TEE) = Basal metabolic rate (BMR) + Thermic effect of food (TEF) + Physical activity (PA)

A substantial amount of total energy expenditure is accounted for by BMR, which is determined principally by body mass and composition, both of which vary with age and sex. The TEF is the energy cost of digesting food and is rarely assessed separately (Department of Health 1991).

Physical activity is a complex, multi-dimensional behaviour. Many different modes of activity contribute to total physical activity; these include occupational, household (*e.g.* caregiving, domestic cleaning), transport (*e.g.* walking or cycling to work) and leisure-time activities (*e.g.* dancing, swimming). Exercise is a subcategory of leisure-time physical activity and is defined as 'physical activity in which planned, structured and repetitive bodily movements are performed to improve or maintain one or more components of physical fitness' (Hardman & Stensel 2003).

Physical activity can be further categorised in terms of the frequency, duration and intensity of the activity. Frequency and duration refer to how often and how long an activity is performed. Intensity refers to how hard a person is working or the rate of energy expenditure that an activity demands.

2.1.2 Intensity of physical activity

The absolute intensity of an activity is the rate of energy expenditure associated with that activity; this is usually measured in kcal/kg/min or METs (which stands for metabolic equivalents). The MET is a unit used to estimate the metabolic cost (energy expenditure or oxygen consumption) of physical activity. One MET is a person's metabolic rate when at rest; this is set as a resting metabolic rate (RMR) of 3.5 ml of oxygen consumed per kilogram of body mass per minute (Westerterp & Plasqui 2004). MET values are given in multiples of RMR, and are assigned to activities to denote their intensity. METs are often used to define categories such as light, moderate and heavy intensity physical activity (Table 1). However, energy expenditure for any given

Table 1 Intensities and energy expenditure for common types of physical activity (adapted from Department of Health 2004)

Activity	Intensity	METs	Energy expenditure (kcal equivalent for a 60 kg person doing the activity for 30 minutes)
Ironing	Light	2.3	69
Cleaning and dusting	Light	2.5	75
Walking – strolling, 2 mph	Light	2.5	75
Painting/decorating	Moderate	3.0	90
Walking – 3 mph	Moderate	3.3	99
Vacuum cleaning	Moderate	3.5	105
Golf – walking, pulling clubs	Moderate	4.3	129
Badminton – social	Moderate	4.5	135
Tennis – doubles	Moderate	5.0	150
Walking – brisk, 4 mph	Moderate	5.0	150
Mowing lawn – walking, using power-mower	Moderate	5.5	165
Cycling – 10-12 mph	Moderate	6.0	180
Aerobic dancing	Vigorous	6.5	195
Cycling – 12–14 mph	Vigorous	8.0	240
Swimming – slow crawl, 50 yards per minute	Vigorous	8.0	240
Tennis – singles	Vigorous	8.0	240
Running – 6 mph	Vigorous	10.0	300
Running – 7 mph	Vigorous	11.5	345
Running – 8 mph	Vigorous	13.5	404

MET, metabolic equivalent.

task depends on body size, so for example a heavy person will expend more energy performing the same task as a lighter person.

Another way of expressing intensity of physical activity is as a percentage of a person's maximal oxygen consumption (VO_2max). Because oxygen consumption and heart rate (HR) during physical activity are so well correlated, the percentage of maximal HR is often used to reflect the relative effect on maximal oxygen consumption (IARC 2002).

2.1.3 Summary measures of physical activity

A whole variety of summary measures are used to quantify physical activity levels. These vary in complexity; many different combinations of duration, intensity and frequency of different types of physical activity have been used. Examples include the total duration of physical activity of a specified intensity (*e.g.* hours per week of moderate-intensity physical activity) or the estimation of total energy expenditure per day or week, or relative to a person's size (*e.g.* kJ/kg/day).

A summary measure that has been used by several health authorities including the Department of Health (Department of Health 1991) is PAL. This is the ratio of overall daily energy expenditure to BMR and is charac-

terised by a description of lifestyle. For example, a person who performs light physical activity at work and is not active in their leisure time might have a PAL of 1.4.

2.1.4 Physical fitness

Physical activity that stimulates the body's cardiorespiratory, musculoskeletal and metabolic systems can, over time, cause them to adapt and become more efficient. In other words, the body gets fitter. Fitness is defined as a set of attributes that people have or achieve that relates to the ability to perform physical activity (US Department of Health and Human Services 1996) (see Fig. 1). While there is often a focus on cardiorespiratory fitness, this is only one element of fitness that can be enhanced through appropriate activity. Other elements include strength, flexibility, speed and power. Optimum levels of body fat are also considered to be an element of fitness (Department of Health 2004).

Cardiorespiratory fitness relates to the ability of the circulatory and respiratory systems to supply oxygen during sustained physical activity (US Department of Health and Human Services 1996). It is sometimes used as a surrogate for physical activity, but because both genetic factors and responses to physical activity dictate cardiorespiratory fitness, and because fitness is also
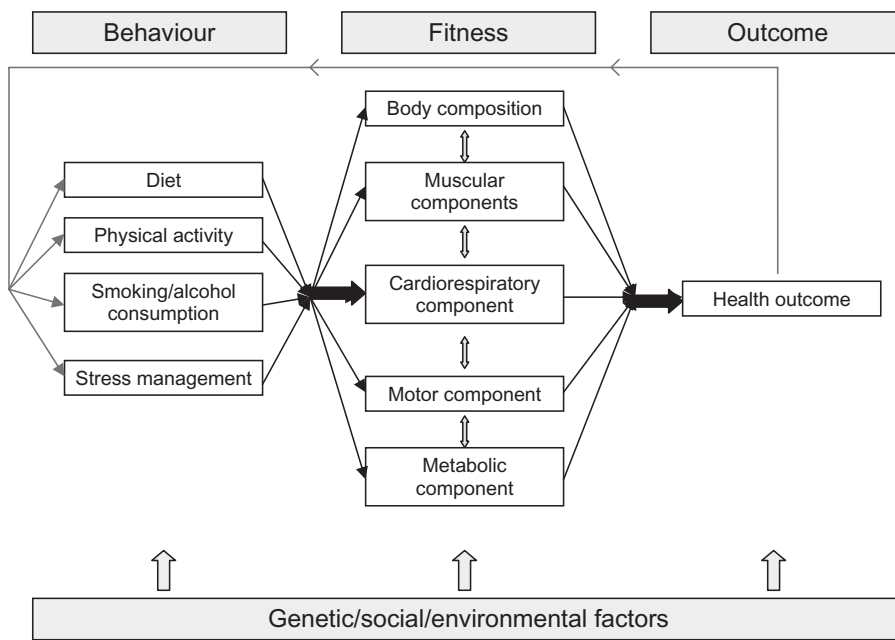
Figure 1 The relationships between behaviour, fitness and health outcomes (adapted from Blair *et al.* 2001).

affected by age, gender and other health habits, it is regarded by some as an inadequate measure of physical activity (Ainsworth *et al.* 1994).

A person's fitness will determine the intensity felt during a specific activity. For example, the Department of Health (2004) has defined moderate-intensity physical activity as that which will usually cause an increase in breathing rate, an increase in HR to the level where the pulse can be felt and a feeling of increased warmth, possibly accompanied by sweating on hot or humid days. The amount of activity needed to experience these feelings will vary from person to person, and this depends on fitness. A fitter body will cope with a specific task more comfortably. Therefore, in some situations it is appropriate to express intensity relative to fitness level (see Table 2) (Department of Health 2004).

The term health-related fitness is used to describe a dimension of fitness that goes beyond pure physical function (Bouchard *et al.* 1994). It encompasses sufficient functional capacity to perform activities of daily living without undue discomfort, optimal weight control, low levels of risk factors for major diseases and optimal psychological and social wellbeing. The main determinants of these attributes are the physical condition of the cardiorespiratory and musculoskeletal systems, regular physical activity, a healthy diet, normal levels of body fat, blood pressure, lipids and insulin sensitivity and good mental health (Department of Health 2004).

Fitness measurements usually focus on CRF (or endurance), muscular fitness and body composition. The best way to measure cardiorespiratory fitness is by

Table 2 Relationships between the different intensities of activities and fitness levels (adapted from Department of Health 2004)

Intensity	Fitness level (maximal METs)			
	High (12 METs)	Moderate (10 METs)	Low (8 METs)	Very low (5 METs)
Very light	<3.2	<2.8	<2.4	<1.8
Light	3.2–5.3	2.8–4.5	2.4–3.7	1.8–2.5
Moderate	5.4–7.5	4.6–6.3	3.8–5.1	2.6–3.3
Vigorous	7.6–10.2	6.4–8.6	5.2–6.9	3.4–4.3
Very vigorous	10.3+	8.7+	7.0+	4.4+
Maximal	12	10	8	5

Values are METs (metabolic equivalents).

assessing maximal oxygen uptake (VO_2max). This is the maximal capacity for oxygen consumption by the body during maximal exertion; it is also known as aerobic power, maximal oxygen consumption and cardiorespiratory endurance capacity (US Department of Health and Human Services 1996). Maximal oxygen uptake decreases with age, so that an activity of a given MET value (an absolute intensity) requires a greater percentage of their maximal oxygen uptake in older people.

Common features of muscular fitness are strength, endurance and flexibility. Muscle strength and endurance are specific to the muscle group so, for completeness, several muscle groups need to be tested. Flexibility is difficult to assess reliably and is specific to the joint

being tested. Balance, agility and co-ordination are also regarded as skill-related aspects of fitness. These aspects of fitness are especially important among older people who are more prone to fall and suffer fractures. Balance stands are sometimes used in assessments and agility and co-ordination are most commonly determined by using a field test such as an agility walk or run. Hydrostatic or underwater weighing are the preferred methods for measuring body composition but these are difficult in some populations, for example children. Other measures include bioelectrical impedance, magnetic resonance imaging, skinfolds, body electrical conductivity and dual-energy x-ray absorptiometry (US Department of Health and Human Services 1996).

2.2 Measuring physical activity

Physical activity is a very complex behaviour that can be measured in many ways. A range of instruments are available for measuring energy expenditure and also physical activity specifically, including objective methods and those based on self-reports. These measures can be used to measure both physical activity and inactivity (sedentary behaviour such as sitting or television viewing), both of which are used for surveillance and research purposes.

2.2.1 Physiological measures of energy expenditure

Methods for monitoring physiological responses to physical activity include direct and indirect calorimetry and the doubly labelled water technique; these all measure total energy expenditure. Direct calorimetry is a method that gauges the body's rate and quantity of energy production by direct measurement of the body's heat production. This method requires subjects to remain in a chamber that measures the heat expended by the body (US Department of Health and Human Services 1996). The indirect calorimetry method differs in that it estimates energy expenditure by measuring respiratory gases. Given that the amount of O_2 and CO_2 exchanged in the lungs normally equals that used and released by body tissues, energy expenditure can be measured by CO_2 production and O_2 consumption. Subjects are required to wear a mask and to carry equipment for analysing expired air (US Department of Health and Human Services 1996). Energy expenditure is usually only measured by direct or indirect calorimetry for a maximum of 24 hours.

The doubly labelled water method for measuring energy expenditure is regarded as a gold standard (Westerterp & Plasqui 2004). The principle of the doubly labelled water technique is that after a loading dose of water labelled with the stable isotopes ^2H and ^{18}O (rather than the more common ^1H and ^{16}O), ^2H is eliminated as water while ^{18}O is eliminated as both water and carbon dioxide. The difference between the two elimination rates is therefore a measure of carbon dioxide production. The rate constants for the disappearance of the two isotopes from the body are measured by mass spectrometric analysis of samples of a body fluid. Energy expenditure is then determined from the carbon dioxide production.

The doubly labelled water technique can be used to measure energy expenditure in free-living subjects for days to several weeks. It has been applied to a wide range of subjects at various activity levels. But because the doubly labelled water technique is expensive this method is only applicable for small study populations. This method provides an accurate measure of total energy expenditure but it does not provide information on physical activity patterns.

2.2.2 Objective methods of assessment

There has been a recent proliferation of motion sensor and HR monitors that provide real-time estimates of the frequency, intensity and duration of free-living physical activity for up to a month. Such direct monitoring methods are often limited by the high cost and burden on subjects and staff. Yet, these methods remain of particular interest for use with children because of their difficulty recording and recalling physical activity (Trost 2001), and in small scale studies.

HR monitors consist of a chest strap transmitter and a small receiver watch. The calculation of energy expenditure from HR is based on the linearity of the relationship between HR and VO_2 during steady-state exercise. It is thought that this linear relationship is strongest during moderate-intensity physical activity with a HR between 110 and 150 beats per minute (bpm) (Rowlands *et al*. 1997; Freedson & Miller 2000). Furthermore, with calibration of the HR-VO_2 curve, an individual's energy expenditure can be calculated.

However, the HR-VO_2 relationship is affected by the relative size of the exercising muscle mass (Rowlands *et al*. 1997), so for example, arm exercise elicits a higher HR than leg exercise at the same VO_2 because of the relatively smaller size of the arm musculature. In addition, comparing HR between individuals may be difficult because of gender, age, body size and training status; those who are less trained would have a higher HR at a given VO_2 than those who are well trained

(Freedson & Miller 2000). The proportion of muscle mass utilised, emotional distress and cardiorespiratory fitness also affect the HR-VO$_2$ relationship. Furthermore, the HR response tends to lag behind the actual activity taking place and it then remains elevated some time after the activity ceases. HR monitoring may also mask the sporadic activity found more commonly in children (Trost 2001).

Pedometers are predominantly used for assessing amount of locomotion by counting steps. The pedometer counts steps by responding to vertical acceleration, triggering a lever arm to move vertically and a ratchet to rotate. They are small and cost-effective, and provide valid assessments of the relative volume of activity performed (Trost 2001). They rarely, however, store data and do not provide any temporal information on the frequency, intensity and duration of physical activity (Freedson & Miller 2000; Trost 2001). Pedometers are not sensitive to activity that does not involve locomotion, isometric exercise, or activity that involves the upper body, for example cycling and stair climbing. Furthermore, step counts are influenced by body size and speed of locomotion, and there is often variability between devices (Freedson & Miller 2000; Trost 2001). Pedometers are, however, very useful in walking intervention studies where subjects are given step count goals that can be self-monitored easily. The various limitations make them less than ideal as an assessment instrument, but if walking activity is the exposure or outcome to be assessed it is useful and inexpensive (Freedson & Miller 2000).

Accelerometers present a lesser burden to subjects as chest straps are not required, and they are capable of detecting intermittent activity patterns and storing data (Trost 2001). Accelerometers can be triaxial, where motion in more than one plane is detected, or uniaxial, where motion in only one plane is detected.

The uniaxial accelerometers usually measure acceleration in a single vertical plane and can be attached to the trunk and/or limbs. The underlying basis of this instrument is that acceleration is directly proportional to the muscular forces and is therefore related to energy expenditure. Both the amount and intensity of movement is measured and the units are small and unobtrusive. They can also have a large memory capacity that allows for monitoring and storage of temporal patterns of activity over a period of days or weeks. An example of a uniaxial accelerometer is the MTI actigraph.

Triaxial accelerometers measure acceleration in the vertical, horizontal and mediolateral planes. Motion is stored as counts over a user-specified time interval for each individual plane, and all planes combined. An example is the Tritrac accelerometer which can estimate total and activity energy expenditure by using a prediction equation to estimate BMR using age, stature, body mass and gender. It is thought that triaxial accelerometers may register more movement than the uniaxial accelerometer (Freedson & Miller 2000).

The data storage capabilities of accelerometers allow for the assessment of the frequency, intensity and duration of physical activity, and, depending on the sampling interval, the intermittent activity patterns of children can be detected (Trost 2001). However, like pedometers, they are insensitive to some forms of activity (*e.g.* cycling, stair climbing), cannot be used in water (so do not detect swimming) and physical activity behaviour may be influenced by their use. Traditionally, the high cost of accelerometers has limited their use to small studies but it is becoming increasingly common to use them in large-scale surveys such as the UK National Diet and Nutrition Survey and the US National Health and Nutrition Examination Survey. Accelerometers are now also used in population studies, particularly in children, such as the European Youth Heart Study and Avon Longitudinal Study of Parents and Children.

2.2.3 Subjective methods of assessment

It is common for physical activity to be assessed using subjective, or self-reported, measures in epidemiological studies. These measures include physical activity diaries, logs and recall surveys. Information obtained is often converted into a summary measure that is then used to categorise or rank the physical activity level of subjects.

Diaries can detail physical activity performed during a specified period (usually 1–3 days, but occasionally up to 7 days) and so this may not represent long-term physical activity or seasonal variation unless repeated over time. They can measure amount and duration of activities, but the intensity of activities is usually estimated. Physical activity logs provide a record of participation in specific types of physical activity rather than all physical activity. For both, there is some inconvenience to the subject and their behaviour may be influenced by the monitoring process (subjects may increase their activity levels so that their records appear more impressive). Recall surveys are less likely to influence behaviour and require less effort by subjects, but have the inherent problems of recall bias. For example, a subject might have the tendency to recall some activities more than others because they are more memorable to them. In general, strenuous activity is recalled more accurately than moderate-intensity activity (IARC

2002). Reference periods for surveys vary from a lifetime to one week (US Department of Health and Human Services 1996).

The possibility of over-reporting of physical activity is an important consideration for all subjective methods. Although further research is needed to investigate the nature of over-reporting, Adams *et al.* (2005) have reported that women with a 'social desirability' personality trait tend to overestimate duration of light and moderate physical activity.

Many types of questionnaires can be used in surveys; these can be global, single item or comprehensive in design. The questionnaires can be self-administered or completed by an interviewer. Global questionnaires compare a person's physical activity with that of other people in general. Single-item questionnaires allow rapid assessment of general patterns of physical activity, for example the frequency of vigorous physical activity likely to promote sweating. Questions often refer to different intensities of activity (*e.g.* strenuous, moderate, mild) with given examples as guidance. A comprehensive questionnaire usually requires recall of time sleeping and in moderate, hard and very hard intensity activities for weekdays and weekend days, with differentiation between work and leisure activities (IARC 2002). It is important to record weekday, weekend and seasonal variation physical activity so that day-to-day variability is captured.

Recall surveys can also involve obtaining histories from subjects. A quantitative history is detailed because it requires recall of physical activity for a year or longer. There is a large memory burden for the subjects and a high cost for administration and interviewer training, quality control and data processing (Caspersen 1989). At least a one year history is required to take full account of seasonality in physical activity. Cognitive interviewing techniques hold promise for lifetime quantitative questionnaires in terms of both the quantity and precision of responses, compared with traditional standardised interviews, but they entail additional costs for interviewer training, time spent in conducting interviews and difficulties in coding the responses (IARC 2002).

2.2.4 Physical activity questionnaires

Self-reported physical activity questionnaires are relatively inexpensive and easy to administer, and so have been the principal tool for surveillance of physical activity in population groups and in epidemiological studies. However, there has been a lack of consensus on the preferred questionnaire for use in these situations.

In response to the global demand for comparable and valid measures of physical activity within and between countries, an international consensus group has developed an International Physical Activity Questionnaire (IPAQ). The purpose of the IPAQ is to provide a set of well-developed instruments that can be used internationally to obtain comparable estimates of physical activity levels. A short version of the questionnaire is suitable for use in national and regional surveillance systems and a long version provides more detailed information often required for research. Fourteen centres from 12 countries have collected reliability and/or validity data on at least two of the eight IPAQ instruments (Craig *et al.* 2003). The IPAQ questionnaire produced repeatable data with comparable data from short and long forms, and there was fair to moderate agreement (median p-value of about 0.30) between the short and long forms in criterion validity against the CSA accelerometer.

The Behavioural Risk Factor Surveillance System (BRFSS) questionnaire is another (interviewer-administered) questionnaire that classifies occupational physical activity, quantifies the frequency and duration of moderate and vigorous leisure physical activity performed during non-working hours in a usual week, and quantifies the frequency of strengthening physical activity in a usual week. Ainsworth *et al.* (2006) have compared the physical activity prevalence estimates from the BRFSS and IPAQ questionnaires in 11 211 US adults. The short interviewer-administered IPAQ was used, which identifies the frequency and duration of moderate and vigorous leisure, transportation and occupational physical activity, walking and inactivity during the past week. When scored using the BRFSS protocol, agreement between physical activity categories was fair, but when scored using their own scoring protocols, agreement between the questionnaires was lower. This study highlights common differences between questionnaires and their implications. The questionnaires differed in the duration of recall, the types and domains of activities queried, the wording and order of questions, and scoring protocols. This and other comparative studies (Brown *et al.* 2004) have demonstrated the difficulty of inter-questionnaire comparison. It is important to be aware that surveys vary greatly in their inclusion of different domains of physical activity.

2.2.5 Choosing an appropriate measurement instrument

Ideally, physical activity should be assessed objectively, with minimum disruption to subjects and so that it is representative of daily life. In order to inform practical

recommendations, it is also important to assess physical activity patterns (*i.e.* frequency, intensity and duration) as well as total energy expenditure (Westerterp & Plasqui 2004). Nevertheless, questionnaires and surveys are most commonly used in epidemiological studies because of their low cost and easy, unrestricted administration to many people.

Various methods of physical activity assessment have their own advantages and disadvantages, and so are more or less suitable for different study objectives. Nonetheless, it is difficult to compare measures of physical activity from different assessment methods. Ainsworth *et al.* (2000) compared three methods of physical activity measurement over a 21 day period. The results showed that motion sensors, physical activity logs and surveys reflect physical activity, but they do not always provide similar estimates of the time spent in resting/light, moderate or hard/very hard activities.

The major factors that require consideration when choosing a physical activity assessment method are presented below:

• scope of the study and outcome of interest, *e.g.* energy expenditure or time spent in moderate-intensity physical activity;
  • nature and details of the physical activity to be recorded, *e.g.* duration, frequency and intensity;
  • the accuracy required of the outcome measurement, *e.g.* absolute measures or ranking to be used;
  • the summary estimate or score to be used to rank or categorise individuals according to their physical activity levels;
• validity/reliability;
• time frame and reference period;
• mode of data collection, *e.g.* interview or self-administered;
• number of subjects *vs.* cost;
• compliance;
• characteristics of the study subjects, *e.g.* age, socio-economic status.

Some special considerations are needed for assessing physical activity in children. Children's activity is highly intermittent and transitory in nature, and so a measurement instrument needs to be sensitive enough to pick up short bursts of activity. Numerous studies have examined the reliability and validity of motion sensors in children under both lab and field conditions, but the general consensus is that they provide valid measures of physical activity, but underestimates of energy expenditure associated with children's intermittent activities (Welk *et al.* 2000). There is also concern about the use of self-report measures in children. The consensus from

several reviews is that previous day recall instruments offer the most promise for use with children, but they are limited by the lack of information on intra-individual variability in activity patterns. Moreover, METs (a measure of intensity) are not well established for various activities in children (Welk *et al.* 2000).

Similarly, measuring physical activity in older adults can present a challenge. Any activity is likely to be more challenging and therefore will be of greater intensity for an older person, than for a younger person doing the same activity. No one method of physical activity assessment is recommended for older people but some authors (Resnick *et al.* 2001; Cyarto *et al.* 2004) advocate the use of pedometers or step monitors.

2.2.6 Validation of physical activity assessment methods

The multitude of difficulties associated with measuring physical activity emphasises the need for validation studies. Validity is defined as the extent to which a measurement instrument assesses the true exposure of interest, which is different to repeatability – the extent to which an instrument gives the same result on different occasions. Both validity and repeatability are important. The ideal validation instrument would objectively measure the true exposure without correlated error (systematic error in the same direction) with the method being validated. An assessment method should be validated against another tool that measures exactly the same exposure. So if a questionnaire is designed to measure total energy expenditure then the validation tool should also measure total energy expenditure (Rennie & Wareham 1998). Many inappropriate comparison methods have been used in this field. For example, Fogel-holm *et al.* (2006) investigated the validity of the short format of the IPAQ questionnaire against fitness. The authors were surprised to find that the dose–response relationship between physical activity and cardiorespiratory fitness disappeared in those classified most active by IPAQ, but put this down to over-reporting of physical activity. Studies using questionnaires which focus on vigorous physical activity may find higher correlations with VO_2max than those that attempt to measure total daily physical activity, because vigorous activities, which are related to fitness, are more reliably recalled in questionnaires. This does not imply that these questionnaires can be used to measure the totality of physical activity.

In addition, it is important to ensure that a validation study uses the same time frame of reference, subjects representative of the population to whom the physical activity instrument will be administered and appropriate

statistical techniques. There is no ideal measurement instrument or validation study design that is suitable for all situations, but a checklist for use when choosing a validation tool is available from Rennie and Wareham (1998).

2.2.7 Physical activity and fitness

Some studies have measured fitness, rather than physical activity, for investigating effects on health outcomes. It is clear that well-established methods used to measure fitness (*e.g.* VO$_2$max) do not have the same inherent problems as those associated with physical activity. Blair *et al.* (2001) have attempted to determine whether physical activity or fitness is a better predictor of health. They observed a stronger inverse relationship between fitness and all-cause mortality, than for physical activity and all-cause mortality. In addition, an analysis of results from the Aerobics Center Longitudinal Study showed that the highest death rates were in the unfit sedentary groups and the lowest death rates were in the highly fit, highly active group (Blair *et al.* 2001). Analyses from this study showed that fitness, rather than physical activity, was inversely associated with mortality.

Nonetheless, it is not possible to determine from these results whether one exposure is better than another as a predictor of health. Both physical activity and fitness relate strongly to health outcomes and act independently; both are very important independent health dimensions. It is likely that these results have been found because fitness has been measured objectively, but physical activity is usually measured by self-report. This inevitably leads to misclassification, and stronger associations for fitness than physical activity. However, a focus on physical activity, rather than fitness, is more practical for public health recommendations.

Key points

• Physical activity is a complex, multi-dimensional behaviour that can be characterised in terms of frequency, duration, intensity and mode.
• Exercise is defined as a subcategory of leisure-time physical activity which is planned and structured and is performed to improve physical fitness.
• Intensity of physical activity is most commonly measured using METs; this is a unit to measure the metabolic cost of an activity. MET values indicate the intensity of an activity and are given in multiples of RMR. One MET is a person's metabolic rate at rest.
• Fitness is defined as a set of attributes that a person has or achieves that relates to the ability to perform physical activity. A person's fitness will determine the intensity felt during a specific activity.
• The doubly labelled water method for measuring energy expenditure is regarded as a gold standard, but it does not provide information about frequency, duration or intensity of specific activities. It is also restrictive and not suitable for measuring physical activity in the long-term.
• Objective measures of physical activity include HR monitors, accelerometers and pedometers. They are often limited in terms of cost and compliance and are not sensitive to all types of physical activity.
• Subjective (self-reported) measures (such as diaries, physical activity logs, recall surveys and questionnaires) are more commonly used in epidemiological studies and surveys; these are limited in terms of reliability and recall bias.
• Validation studies can be helpful for assessing the appropriateness of a physical activity tool, but it is important that the validation tool and the measure being validated both relate to the same exposure.
• A perfect instrument that can effectively quantify the level and patterns of physical activity does not yet exist. The resulting measurement error is likely to weaken the strength of observed relationships between physical activity and health, and weaken the effects of interventions.
• Various dimensions of physical activity (*e.g.* moderate-intensity activity, frequency of activity) may affect distinct health outcomes differently; and it is not always clear that the dimension with the greatest effect on health has been measured in studies.
• Fitness can be measured objectively and so in some cases stronger associations are seen between fitness and disease outcomes, compared with those observed between physical activity and disease outcomes.

3 Physical activity levels in the UK

3.1 Physical activity levels in UK adults

A measure of physical activity levels in UK adults is provided by the Health Survey for England, an annual survey of health measures and demographics. Using a seven-day recall method, physical activity levels are measured against the current UK recommendations; for adults this is 30 minutes of at least moderate-intensity activity on at least 5 days of the week (Department of Health 2004). In 2004, 35% of men and 24% of women were achieving this level of physical activity (Table 3). There was a decline in activity levels with age, and activity levels were greater in men than women for

Table 3 Percentage of adults (aged 16 years and over) achieving the UK physical activity guidelines[†], by age and gender, for 1997, 1998, 2003 and 2004

Age (years):	All ages	16–24	25–34	35–44	45–54	55–64	65–74	75+
Men								
1997	32	49	41	37	32	23	12	7
1998	34	53	45	41	34	30	14	6
2003	35	53	44	41	37	32	17	8
2004	35	56	46	41	37	32	19	9
Women								
1997	21	26	26	29	24	19	8	5
1998	21	28	28	28	25	18	9	3
2003	24	30	29	30	30	23	13	3
2004	24	31	31	33	29	19	14	4

[†]A minimum of 5 days a week of 30 minutes or more of moderate-intensity activity (only episodes of activity lasting 30 minutes or more were included). For comparative purposes, only unweighted values are included in the tables.
Source: Health Survey for England – updating of trend tables to include 2004 data (The Information Centre, Lifestyle Statistics 2006).
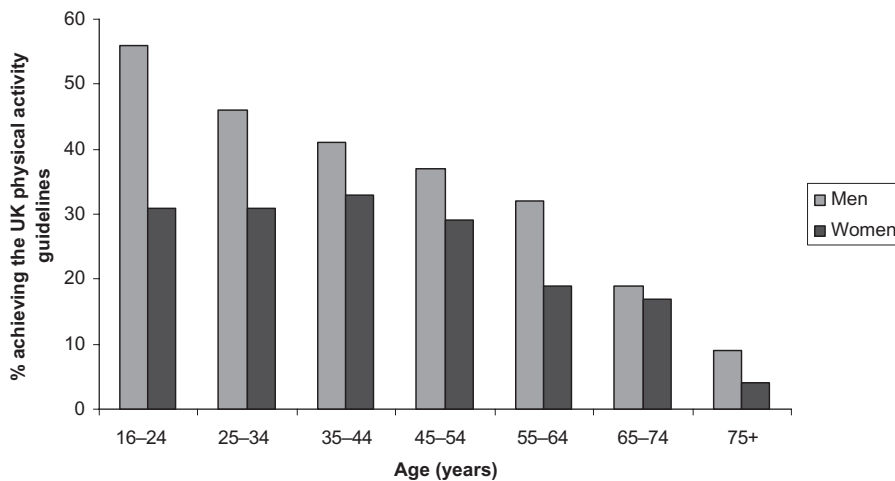
Figure 2 Percentage of adults achieving the UK physical activity guidelines* by age and gender in 2004.
*A minimum of 5 days a week of 30 minutes or more of moderate-intensity activity (only episodes of activity lasting 30 minutes or more were included). Source: Health Survey for England – updating of trend tables to include 2004 data (The Information Centre, Lifestyle Statistics 2006).

all age groups (see Fig. 2). For men, the 16–24 years age group were best at reaching the physical activity recommendation (56%) and for women this was the 35–44 years age group (33%). Both men and women aged 75 years and over were the least likely to meet the physical activity recommendations.

The Health Survey for England 2003 also provides information on the types of activities that English adults engage in (The Information Centre, Lifestyle Statistics 2006). Walking is done by about one quarter to one-third of adults, and participation in walking remains relatively stable throughout adult life, until age 55 years and above when it declines. Sports and exercise are most common in young men aged 16–34 years, and heavy housework is common in women aged 25–64 years. Heavy/manual work, gardening and DIY are activities more commonly performed by men than women at all ages.

The physical activity levels of UK adults have also been assessed in the National Diet and Nutrition Survey (Ruston *et al*. 2004). Methods involved seven-day physical activity diaries, and self-reports of overall activity level. These self-reports of physical activity are presented in Table 4. Results from this survey show a less marked decrease in physical activity with age. Around 50% of the population described themselves as fairly active. A large gender difference was seen in young adults (19–24 years), where 26% of men and 12% of women described themselves as very physically active. Levels of moderate and vigorous physical activity were assessed using the seven-day activity diary. In the seven-day recording period the mean time spent doing at least moderate activity was 2.2 hours for men and 1.2 hours for women. The mean time spent doing vigorous or very vigorous activity was 0.5 hours for men and 0.1 hours for women.

Table 4 Percentage distribution of self-reported levels of physical activity by age and sex

Reported level of activity	% Men aged (years):					% Women aged (years):				
	19–24	25–34	35–49	50–64	All	19–24	25–34	35–49	50–64	All
Not at all physically active	7	4	5	5	5	8	6	5	8	6
Not very physically active	24	23	25	20	23	27	23	26	22	24
Fairly physically active	43	53	52	53	51	53	57	48	52	52
Very physically active	26	21	18	21	21	12	15	20	18	17

Source: National Diet and Nutrition Survey, adults aged 19 to 64 years, Volume 4 (Ruston *et al*. 2004).

The Low Income Diet and Nutrition Survey (Nelson *et al*. 2007) has provided a useful insight into physical activity levels in low-income groups. Based on self-reported data, this survey showed that 76% of men and 81% of women undertook less than one 30 minute session of moderate or vigorous activity a week. Only 11% of men and 8% of women undertook 30 minutes of continuous activity of moderate- or vigorous-intensity at least 5 days a week. This is substantially less than for the general population. Hence, there is some suggestion that physical inactivity is linked to low income and lack of employment.

The Health Survey for England provides some information on ethnic differences in physical activity levels. Compared with the general population, data from 2004 show that more individuals from Indian, Pakistani, Bangladeshi and Chinese ethnic groups have a low level of physical activity (less than one 30 minute moderate or vigorous activity session a week) (The Information Centre, Lifestyle Statistics 2006).

3.1.1 Temporal trends

Gathering data on temporal trends in physical activity is important for identifying population subgroups at high risk of physical inactivity. This information can also be used to evaluate public health interventions, enhance our understanding of dose–response relationships, and help develop population-specific physical activity interventions. Table 3 shows the recent trends in the percentage of adults achieving the UK physical activity guidelines. Unfortunately, the trend data are only available for a short time period. With the exception of women aged 55–64 years and 75+ years, physical activity increased between 1997 and 2004.

Stamatakis *et al*. (2007) have completed a more detailed analysis of the temporal trends in physical activity using data from the Health Survey for England from 1991 to 2004. This work focused on adults (16 years and over) and measured physical activity levels against current recommendations (at least 30 minutes of moderate-intensity activity five times a week). From 1991 to 2004, there were some changes in the questions used to measure physical activity, especially for time spent walking and in domestic activity. Unfortunately, modification of the methodology precludes the presentation of a clear picture of the total temporal trends in physical activity in England for this time period.

Between 1999 and 2004 (a period when questions on physical activity participation remained unchanged) there were significant increases in average time spent in all activity types. Overall, the number of adults meeting the recommendations increased from 46.8% in 1999 to 48.5% in 2004; these short-term increases were marked among adults aged 35–64 years. Over the same time period, the average weekly time spent in moderate-intensity walking increased from 50 to 60 minutes in men and from 38 to 50 minutes in women. Similarly, average weekly time spent in moderate-intensity domestic activity increased from 106 to 118 minutes in men and from 104 to 114 minutes in women.

However, significant declines in occupational activity were observed for both men (43.4% to 38.5% active in work) and women (27.3% to 24.7% active in work) from 1991/2 to 2004. Yet, an upward trend in sports participation in all age groups has been observed over the same time period. This increase was marked in the 35–49 years age group: the percentage of men who regularly participated in sport increased from 26.0% to 42.6%, and women who regularly participated in sport increased from 25.1% to 35.4%. When specific activities were considered, a decline in cycling was seen but there were increases in weight training, fitness/health club exercises, and general strength exercises (*e.g.* push-ups). These changes have taken place alongside an increase in the prevalence of obesity (Zaninotto *et al*. 2006) and so this leads to speculation as to how changes in activity levels have influenced obesity. It is possible that the net change in physical activity considering the increase in sports participation, together with the decline in occupational activity, is still negative. It is also possible that data on trends are limited by self-reports of

physical activity. Awareness that physical activity is good for health may lead to biased overestimates of physical activity levels and changes in this awareness may change bias over time.

3.2 Physical activity levels in UK children and adolescents

Table 5 shows a summary of children's physical activity levels, derived from the Health Survey for England (2002). Children are clearly more active than adults: 70% of boys and 61% of girls achieve the recommended 60 minutes of physical activity on all seven days of the week (Department of Health 2004). Boys tend to be more active than girls at all ages, and there is a decline in physical activity as children reach adolescence. There is a steep decline in activity in adolescent girls; 35% of 14- to 15-year-old girls achieve less than 30 minutes of activity per day. These observations have been repeatedly reported in the literature (Biddle *et al*. 2004; Henning Brodersen *et al*. 2006; Riddoch *et al*. 2007).

Physical activity levels were also assessed in the National Diet and Nutrition Survey of young people aged 4–18 years (Gregory & Lowe 2000). The physical activity of 4–6 year-olds was assessed using three questions in the dietary interview and participants aged 7–18 years were asked to complete a seven-day activity diary. The majority of 4–6 year-olds reported that they had about the same activity level as others of the same age (69% of boys and 74% girls), but approximately a quarter reported that they were more active than those of the same age. When parents assessed activity levels, 53% of boys (4–6 years) and 64% of girls (4–6 years) were thought by their parents to be fairly active, and 43% of boys and 29% of girls were thought to be very active. The amount of moderate and vigorous activity performed by 7–18 year-olds is presented in Table 6. Again, there is an indication that young boys are more active than girls, and there is a decline in activity levels (particularly moderate intensity) in adolescents.

Both the National Diet and Nutrition Survey and the Health Survey for England rely on self-reports of physical activity. However, it is thought that objective techniques are more valid and generalisable than self-reports (see Section 2.2) and their use in epidemiological studies is increasing. Accelerometry is a particularly useful measure of physical activity in children because it can detect informal play. Using accelerometry, Riddoch *et al*. (2007) reported that only 2.6% of children (boys 5.1% and girls 0.5%) met current guidelines for 60 minutes of moderate-intensity activity per

Table 5 Summary of children's physical activity levels, by age and gender, 2002

Age (years):	All ages	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Boys															
High (%)	70	67	76	73	67	70	71	68	69	72	77	71	69	62	69
Medium (%)	13	13	12	15	17	14	15	14	14	12	9	11	17	14	14
Low (%)	17	20	12	12	17	16	14	18	17	16	14	18	15	24	17
Girls															
High (%)	61	65	78	65	66	69	65	62	62	66	64	52	50	44	50
Medium (%)	16	12	11	14	16	13	13	19	15	17	16	22	23	21	15
Low (%)	22	23	11	21	18	18	22	19	23	17	20	26	27	35	35

High = 60 minutes or more on all 7 days; medium = 30–59 minutes on all 7 days; low = lower level of activity.
Source: Health Survey for England (Department of Health 2002).

Table 6 Mean number of hours young people aged 7 to 18 years spend in moderate and vigorous/very vigorous intensity activities

Age (years)	Male				Female			
	7–10	11–14	15–18	All	7–10	11–14	15–18	All
Mean hours spent in moderate-intensity activity	1.3	1.1	0.7	1.0	0.8	0.7	0.6	0.7
Mean hours spent in vigorous/very vigorous intensity activity	0.3	0.4	0.3	0.4	0.3	0.3	0.2	0.3

Source: National Diet and Nutrition Survey, young people aged 4 to 18 years (Gregory & Lowe 2000).

day. It is therefore possible that self-report methods used in large surveys have overestimated physical activity in children.

The Low Income Diet and Nutrition Survey (Nelson *et al*. 2007) also demonstrated that children from low-income families had lower levels of physical activity. Twenty-six per cent of boys and 31% of girls aged 2–10 years and 34% of boys and 38% of girls aged 11–15 years achieved the recommended 60 minutes of physical activity on all seven days of the week. Furthermore, 52% of boys and 49% of girls aged 2–10 years, and 28% of boys and 41% of girls aged 11–15 years were on average active for less than 30 minutes every day.

Henning Brodersen *et al*. (2006) have examined the physical activity patterns of adolescents in terms of ethnic and socioeconomic differences. Asian adolescents were less physically active than white adolescents, whereas sedentary behaviour was higher in black adolescents. Black adolescent girls were less active than white girls, but this pattern was not observed in boys. Sedentary behaviour was greater in the low-socioeconomic-status groups. Ethnic and socioeconomic differences are largely established by age 11–12 years (Henning Brodersen *et al*. 2006).

3.2.1 Temporal trends

The availability of data on trends in physical activity in children is limited to a short time period. According to the Health Survey for England, the proportion of children meeting current recommendations for physical activity has remained relatively stable from 1997 to 2002, although an increase has been seen in girls aged 11–15 years (Table 7). However, in all age groups the proportion of children who achieve less than 30 minutes per day of physical activity has decreased over this time period.

Yet, there is a frequent assumption in the academic and popular media that young people today are less active than in previous generations. This is difficult to assess because comparisons across surveys and time are limited by the different measures that have been used. There is some evidence that clearly defined contexts of physical activity are declining in children, but evidence that considers total physical activity fails to support this assumption (Dollman *et al*. 2005).

Biddle *et al*. (2004) suggest that personal transport patterns are changing and energy expenditure appears to have declined in children. There is a dramatic decline in active transport to school. It is thought that an increase in perceived danger by parents has led to a decline in the number of children who walk to school

Table 7 Summary of children's physical activity levels, in 1997 and 2002

	1997	2002
Boys 2–10 years		
High (%)	54	55
Medium (%)	9	20
Low (%)	37	26
Boys 11–15 years		
High (%)	55	56
Medium (%)	13	16
Low (%)	33	29
Girls 2–10 years		
High (%)	45	48
Medium (%)	10	21
Low (%)	44	30
Girls 11–15 years		
High (%)	27	34
Medium (%)	15	22
Low (%)	59	44

High = 60 minutes or more on all 7 days; Medium = 30–59 minutes on all 7 days; Low = lower level of activity.
It was assumed that all activity was of at least moderate intensity.
Source: Health Survey for England (Department of Health 2002).

alone. From 1975/76 to 1989/94 this has been associated with a decrease in the number of 5–10 year-old British children walking to school from 71% to 62%, and an increase in car usage from 15% to 28% (Dollman *et al*. 2005).

When considering sedentary behaviour, it appears that the amount has remained remarkably stable, but the content and type of media has changed. A recent survey by Sport England (2003) showed no change in the number of hours of weekly TV viewing for young people between 1999 and 2002. The same survey reported no change in participation in curriculum-based school sports, and involvement in extracurricular sports organised by schools increased slightly from 4.2 to 4.6 types of sport per child.

However, there is some indication that time spent in school physical education lessons has declined in the UK (Harris 1994). Evidence suggests that pressure to provide time in the curriculum for more vocationally orientated learning is seriously affecting the status of physical education in schools.

Overall, it appears that despite a decline in physical activity in particular contexts, physical activity levels in children remain relatively stable. A child's general acceptance of physical activity is high, and it is perceived to be enjoyable (Dollman *et al*. 2005).

Key points

• Physical activity levels in the UK are low. Only 35% of men and 24% of women reach the recommended 30 minutes of moderate-intensity physical activity at least five times a week.
• There is a marked decline in physical activity with age in both men and women.
• Men tend to be more active than women at all ages.
• In the UK, changes in survey methods have hindered the monitoring of long-term physical activity patterns but it is clear that the percentage of adults that meet the UK physical activity recommendations has increased from 1997 to 2004 (with the exception of older women).
• There has been a decline in occupational physical activity from the 1990s onwards, but an upward trend in sports participation, *e.g.* joining fitness clubs, over the same time period.
• Children are more active than adults. Seventy per cent of boys and 61% of girls reach the recommended 60 minutes of moderate-intensity physical activity per day.
• Boys tend to be more active than girls and there is a decline in physical activity as children reach adolescence, which is more marked in girls.
• Overall, physical activity levels in children have been relatively stable in recent years. But there is some evidence to suggest a decrease in active transport to school and time spent in school physical education lessons.
• Lower-income groups have particularly low physical activity levels and there is some evidence that physical activity is lower in some ethnic minority groups.

4 Physiological effects of physical activity

4.1 Energy balance

As discussed in Section 2.1, physical activity is an important component of total energy expenditure. The amount of energy expended performing a particular activity depends on the muscle mass involved and the intensity at which the activity is performed; specific activities tend to range from 2 to 18 METs. Different activities lead to a large variability in physical activity; physical activity levels ranging from 1.2 to 2.2–2.5 have been reported in healthy adults. Although an increase in total energy expenditure is expected from physical activity, it has been shown that there is an additional increase in total energy expenditure that is not directly due to the activity-induced energy expenditure from physical activity (PAEE).

4.1.1 Resting metabolic rate

Exercise intervention studies in animals generally show that single exercise events and longer-term training produce increases in RMR. This effect is observed in longer-term interventions despite parallel decreases in body mass and fat mass (Speakman & Selman 2003). As RMR is the greatest component of total energy expenditure, physical activity-induced changes to RMR make an important contribution to increases in total energy expenditure.

We know that there is considerable variation in RMR in humans, and that a major contributory factor is variation in lean body mass; this accounts for approximately 50–70% of individual variation. Physical activity can affect RMR by increasing lean tissue and by changing physiological processes that influence resting metabolism. Both of these are long-term processes taking place as a result of protracted periods of physical activity training.

There are many human studies that have examined the influence of exercise on RMR in the short-term, but these studies have generated mixed results (Speakman & Selman 2003). An important consideration that may explain some of the inconsistency in study results is the timing of RMR measurement relative to the termination of the last exercise bout. This is because there are increases in residual RMR that occur over short periods of time following single bouts of exercise. This transient change is over too short a time scale to involve any alteration in lean tissue mass. Such post-exercise increases in RMR have been termed excess post-exercise oxygen consumption (EPOC) (Van Baak 1999; Speakman & Selman 2003).

Estimations of EPOC vary between 125 and 625 kJ depending on the duration and intensity of exercise, but EPOC is always smaller than the amount of energy expended during the exercise bout itself (Van Baak 1999). EPOC appears to have two phases: one lasting <2 hours and a smaller much more prolonged effect lasting up to 48 hours. Research investigating the effects of physical activity on RMR is potentially limited because some studies measuring RMR do not continue to monitor it for sufficient time after the last exercise bout to capture the termination of the long-term EPOC. If the measurement of post-exercise RMR is conducted within 48 hours of exercise it is likely that an effect on RMR will be detected. This is not a long-term training effect on metabolism, but rather detection of the long-term EPOC following the last exercise event (Speakman & Selman 2003).

Short-term physiological changes associated with EPOC include elevated body temperature and increases in fat metabolism. The magnitude of the long-term EPOC is thought to be an increase of about 5–10% in RMR and can be seen as late as 48 hours after exercise;

this can add up to a sizeable energy cost over time (Van Baak 1999). The physiological processes involved in longer-term EPOC are not clear, but there is some suggestion that the β-adrenergic system is involved because β3 adrenoreceptors are involved in controlling RMR.

4.1.2 Non-exercise activity thermogenesis

It is also possible that increases in non-exercise activity thermogenesis (NEAT) contribute to the additional increase in total energy expenditure in response to physical activity (van Baak 1999). NEAT refers to minor movements and general walking around (*e.g.* walking from room to room at home or in the workplace). Speakman & Selman (2003) have proposed that as physical activity can improve fitness, other behaviours, particularly the NEAT component of the daily energy budget, might increase as individuals get fitter and lose weight. For example, fitter people may be more inclined to walk rather than use the car, or take stairs rather than lifts, and so behavioural changes such as these would increase the total energy expenditure as a result of the exercise. Figure 3 shows how the energy expended as a result of an increase in physical activity is much larger than predicted from the energy expenditure associated with the activity alone. These additional increases in energy expenditure are thought to be important contributory factors to why those who engage in moderate to high levels of physical activity are able to maintain energy balance more easily than those who are largely sedentary.

4.2 Body composition

Physical activity can increase lean body mass; this is done by increasing the mass of skeletal muscles used

performing the physical activity. Furthermore, structural changes take place in the muscles whereby they increase in capillary density and also potential for glycogen storage.

Physical activity can also modify body composition favourably by reducing fat mass. Even when an exercise programme produces no loss in bodyweight, substantial reductions in abdominal subcutaneous and visceral fat can be achieved (McArdle *et al.* 2007). Broeder *et al.* (1997) has shown that 12 weeks of both resistance and endurance training can produce significant decreases in fat mass and percentage body fat. Theoretically, 30 minutes of moderate physical activity per day is equivalent to approximately 1500 kcal/week, which translates to a loss of 2.1% or 1.8% body fat for men and women respectively (Elder & Roberts 2007).

Nevertheless, epidemiological studies that have examined the relationship between physical activity and percentage body fat have not produced as strong an evidence base as might be expected. A number of studies have reported unexplained gender differences in the relationship between physical activity and body fat. Paul *et al.* (2004) reported that total energy expenditure was related to percentage body fat in women but not men, but that physical activity energy expenditure was significantly related to percentage body fat in men but not women. In a review, Elder & Roberts (2007) reported a stronger association in women and proposed that the steeper slope in the relationship between exercise and body fat in women is due to highly active women having greater concern about their body fat, which leads them to practise other behaviours that influence energy regulation.

Similarly, different relationships between physical activity and percentage body fat have been reported for
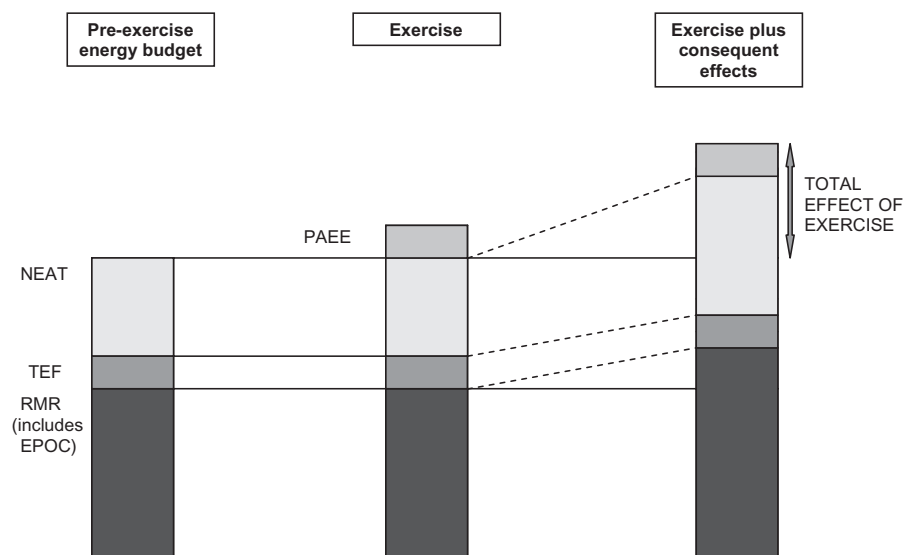

Figure 3 Consequences of exercise on energy expenditure (adapted from Speakman & Selman 2003). PAEE, physical activity energy expenditure; NEAT, non-exercise activity thermogenesis; TEF, thermic effect of food; RMR, resting metabolic rate; EPOC, excess post-exercise oxygen consumption.

different age groups. Using accelerometry as a measure of physical activity in children (aged 12 years), Ness *et al.* (2007) demonstrated a strong graded inverse association between moderate and vigorous physical activity and fat mass. Ekelund *et al.* (2005a) reported that in adolescents, physical activity was independently inversely associated with fat mass, percentage fat mass and body mass index (BMI) in boys but not girls. In a prospective study of middle-aged healthy whites, baseline physical activity energy expenditure predicted a change in fat mass in younger adults, who as a group gained weight in this study. Yet in the same study, baseline physical activity energy expenditure in older adults (who were on average weight stable) was associated with a gain in bodyweight, which was explained by an increase in fat mass and fat-free mass (Ekelund *et al.* 2005b).

It is likely that the variation in methodology used for measurement of physical activity, energy expenditure and body composition, and in particular the major reliance on self-reported measures of physical activity, limits the research in this area and contributes to the inconsistency in study results (see Section 2.2). In addition, body composition is also affected by energy intake, and it is possible that interactions between physical activity and energy intake, via changes in appetite or food choice, might explain why there is some variation in the effectiveness of physical activity in changing body composition (see Section 4.3).

4.3 Interaction with food intake

Physically active individuals are able to consume a greater amount of energy to achieve energy balance, compared with those who are sedentary. Such greater energy intakes have consequences in terms of the nutrient density of the diet. In effect, increasing the amount of food needed to match energy expenditure may lessen any potential problems with micronutrient deficiencies; achievement of adequate micronutrients is more difficult in an energy-restricted diet.

4.3.1 Energy intake and appetite

A number of authors have described the short-term effects of physical activity on energy intake. Overall, it is well documented that, in the short-term, there is a weak association between energy expenditure and energy intake following exercise (King 1999; Blundell *et al.* 2003; Melzer *et al.* 2005; Elder & Roberts 2007). So, there is no immediate increase in energy intake to compensate for the energy expended during exercise. The lack of any compensatory energy intake increase could

be explained by changes in hunger. Elder and Roberts (2007) found that most studies report that perceived hunger is reduced or that eating is delayed immediately following a bout of exercise.

King *et al.* (1994) suggest that the impact of exercise on hunger depends on the intensity of the exercise. Short-term low-intensity exercise did not induce a suppression of hunger, but high-intensity exercise did. Further work by King *et al.* (1997a) demonstrated that a substantial but acute increase in energy expenditure due to intense exercise does not automatically increase hunger or energy intake within 48 hours. Melzer *et al.* (2005) have proposed that the decrease in hunger could be a result of increased blood glucose, free fatty acids and plasma lactate levels during and after short-term exercise; such mobilisation of fuels may have an important role in the inhibition of energy intake. In addition, King *et al.* (1997b) reviewed studies reporting the effects of exercise on appetite control in humans and concluded that an elevation of body temperature, increased levels of lactic acid and an increase in tumour necrosing factor are plausible mechanisms for a decrease in hunger.

Blundell *et al.* (2003) have indicated that short-term (1–2 days) and medium-term (7–16 days) studies demonstrate that men and women can tolerate a substantial negative energy balance of ≤4 MJ energy cost per day when performing physical activity programmes. However, only three of 16 long-term intervention trials reviewed by Elder and Roberts (2007) found a significant change in energy intake resulting from the exercise intervention; one reported a decrease in energy intake and two an increase in energy intake. Furthermore, King (1999) has highlighted that there is a positive relationship between physical activity and food intake in the free-living population. It appears that negative energy balance induced by an increase in physical activity cannot be maintained in the long-term. The weak coupling between exercise-induced energy expenditure and energy intake as a result of the lack of compensation cannot continue indefinitely, because the body cannot tolerate a persistent loss in weight. It is therefore likely that a period of transition, where energy expenditure can exceed energy intake, occurs in the short-term, before a steady-state condition ensues, in which energy balance is achieved (King 1999).

Blundell *et al.* (2003) have recognised that there are variable responses to physical activity in terms of energy intake compensation. Some individuals performing activity with a daily energy cost of ≤4 MJ show no change in daily energy intake, whereas others will increase their energy intake. Energy compensation is thought to differ among lean and obese individuals.

Overall, when exercised on a long-term basis, it seems that obese individuals do not match their energy intake to energy expenditure through physical activity, but lean subjects demonstrate an increase in energy intake and insignificant changes in body mass (Melzer *et al.* 2005). In the obese, adipose tissue can act as an energy buffer, so compensatory responses in intake to altered levels of activity may not begin until the excess energy stores become depleted and energy homeostasis is at risk. At the other extreme, well-trained athletes, who expend enormous amounts of energy, tend to match energy expenditure with energy intake, and maintain energy balance so as to avoid poor performance due to persistent weight loss (Melzer *et al.* 2005).

Both physiological and psychological processes are thought to be involved in driving long-term energy compensation in response to physical activity. In terms of physiological processes, a reduction in RMR and reduced exercise-induced energy expenditure (both as a result of weight loss) have the potential effect of gradually reducing the total energy expenditure until a steady state is reached. But King (1999) has proposed that there are also a number of behavioural processes that come into play, such as an increase in food intake or a decrease in non-exercise activity. An indication that psychological processes are important is suggested by the interesting observation that food deprivation significantly increases hunger and energy intake whereas an exercise-induced energy deficit does not. This would not be expected if physiological processes alone explained energy compensatory responses to physical activity. The psychological profile of an individual, in particular tendencies for dietary restraint and reasons for exercising, could have a very strong influence on the food intake response to exercise. For example, someone who has increased their activity levels to lose weight is likely to have a different response in terms of food intake compared with an endurance athlete whose objective is to optimise athletic performance. However, in terms of lowering overall energy expenditure, there is evidence to suggest that individuals do not compensate for the increase in exercise-induced energy expenditure by becoming more sedentary (King 1999).

4.3.2 Macronutrient intake

Although difficult to assess, Elder and Roberts (2007) have reviewed the effects of exercise on macronutrient intake. Although several studies found a significant difference in macronutrient intake between active and inactive subjects, overall there was inconsistency in the results. There were some slight trends observed: active men tended to consume more carbohydrate, and less fat and protein than inactive men, but the trend was not significant; active women tend to consume more fat than inactive women but again the trend was non-significant. Very short-term intervention trials examining the acute effects of a single bout of exercise on macronutrient intake also show mixed results. Elder and Roberts (2007) concluded that there is no evidence to suggest that long-term exercise training influences macronutrient intake. However, King (1999) highlighted that there are a few studies that show an increase in carbohydrate intake in response to exercise. These results could be explained by physiologically induced factors as a result of glycogen depletion, or it might be because more carbohydrate-rich fluids and foods are consumed during and after exercise.

4.3.3 Utilisation of energy substrates

Substrate utilisation is affected by activity, and this depends on the intensity of the activity (van Baak 1999). At low exercise intensities (25% VO_2max), such as walking at 4–5 km/hour, energy is almost solely provided by oxidation of fatty acids; 85% of the fatty acids are from plasma. At higher intensities (85% VO_2max), such as running at 9 km/hour, less than 30% of energy is derived from oxidation of fatty acids; approximately half of the fatty acid oxidation is derived from oxidation of plasma-free fatty acids. Instead the majority of the energy is derived from muscle glycogen. So with increasing exercise intensity there is a shift from the relative utilisation of fats to carbohydrate and from plasma-derived substrates to intramuscular substrates. Also, with more prolonged exercise, the contribution of fat utilisation will increase at the cost of carbohydrate utilisation. There is also an effect on substrate utilisation after exercise has ceased. In the first few hours after an exercise bout, fat utilisation appears to be increased and resting fat utilisation can be increased as much as 36 hours after the exercise bout (Van Baak 1999).

Importantly, an adaptation takes place in those individuals who regularly engage in physical activity. Well-trained individuals will usually oxidise more fat and will utilise less muscle glycogen at a given percentage VO_2max (van Baak 1999). The utilisation of fat as an energy substrate has important implications for energy balance because short-term consumption of a high-fat diet is thought to be a factor in excess fat accumulation. Whereas carbohydrate oxidation quickly adjusts to balance changes in dietary carbohydrates, fat oxidation adjusts much more slowly to acute changes in dietary fat. Feeding studies by Hansen *et al.* (2007) have shown that exercise enhances the ability to increase 24 hour fat

oxidation in response to increasing intakes of fat in the diet. An increase in physical activity led to a greater increase in the 2 hour fat oxidation for PALs of 1.4, 1.6 and 1.8, respectively, after the transition time from a low-fat control diet to a high-fat diet.

4.4 Cardiovascular effects

4.4.1 Blood pressure

It is well known that during exercise, blood pressure increases, particularly when the exercise activates a large muscle mass and requires a relatively great muscle strain (McArdle *et al*. 2007). Exercising the body's large muscles increases cardiac output several fold. Vasodilation of the arterioles in the exercising muscles causes a decrease in peripheral resistance which, in turn, attenuates the rise in blood pressure which would otherwise follow from the increase in cardiac output (Hardman & Stensel 2003). When exercise ceases, cardiac output quickly falls back to pre-exercise levels, but the vasodilation and decrease in peripheral resistance persists for hours. This hypotensive post-exercise response can last for up to 12 hours (McArdle *et al*. 2007). In this way, individuals who exercise regularly spend a substantial amount of their time in a state of post-exercise hypotension.

It is therefore not surprising that, in a meta-analysis of 72 trials, Cornelissen and Fagard (2005) showed that endurance training for ≥4 weeks induced significant net reductions of resting and daytime ambulatory blood pressure of 3.0/2.4 mmHg and 3.3/3.5 mmHg respectively. The effect was more pronounced in those with greater baseline blood pressure. Mechanisms involved a reduction in vascular resistance (as described above), but in addition, it was thought that the sympathetic nervous and rennin-angiotensin systems are involved because it was observed that plasma noradrenaline decreased by 29% ($p < 0.001$), and plasma rennin by 20% ($p < 0.05$).

4.4.2 Coronary vascular transport and endothelial function

Laughlin and McAllister (1992) have described how aerobic exercise training induces an increase in the capacity to carry blood in the coronary arteries. This is the result of an increase in the size of coronary arteries (Hardman & Stensel 2003) and thus increases in blood flow capacity and capillary exchange capacity. Structurally, physical activity causes increases in the cross-sectional area of the proximal coronary arteries and the formation of new blood capillaries (angiogenesis), and physical activity has also been shown to alter coronary vascular control.

Endothelial function refers to the ability of the endothelium (thin layer of cells lining blood vessels) to interact with vascular smooth muscle and induce vasodilation or vasoconstriction. Nitric oxide is a major vasodilator that is released by endothelial cells. Thus, nitric oxide is important for increasing blood flow when required, and its release is increased during exercise. Physical activity induces improvements in endothelial function by increasing the activity of nitric oxide synthase, which produces nitric oxide, and increasing extracellular superoxide dismutase, which prevents breakdown of nitric oxide. These processes are all crucial for directing the appropriate distribution of blood in the body. Furthermore, endothelial dysfunction is thought to occur in the early stages of atherosclerosis and is a trigger for ischaemia (Hardman & Stensel 2003).

4.4.3 Coagulation and fibrinolysis

Coagulation refers to the formation of blood into a clot or thrombus, and is involved in CVD. The final event in the coagulation cascade is the conversion of the plasma protein fibrinogen into fibrin, which then traps blood cells to form a blood clot. The opposite process is fibrinolysis, which involves the breakdown of fibrin and blood clots. A key stage in the fibrinolysis process is the activation of the proenzyme plasminogen to the enzyme plasmin. The plasminogen activator (t-PA) is secreted by endothelial cells, so high concentrations of t-PA enhance fibrinolysis. However, an inhibitor – plasminogen activator inhibitor-1 (PAI-1) – is known to inhibit the fibrinolysis process. Although acute exercise can be considered a pro-coagulant state, regular physical activity has been shown to exert benefits on both coagulation and fibrinolysis, via reduced platelet aggregation, reductions in plasma fibrinogen and PAI-1 concentrations and an increase in t-PA concentration (Hardman & Stensel 2003).

4.5 Lipid profile and cholesterol

There is substantial evidence showing that aerobic exercise training produces favourable changes in plasma lipids and lipoproteins. Lipid and lipoprotein changes following resistance training are usually not found. Table 8 summarises the effects of aerobic exercise on lipids and lipoproteins, as reviewed by Durstine *et al*. (2002). Plasma triglyceride concentrations are usually, but not always, decreased in response to exercise:

Table 8 Changes in lipids and lipoproteins with exercise

Lipid/lipoprotein	Single exercise session	Regular exercise participation
Triglyceride	Decreases of 14–50% (mean = 20%)	Decreases of 4–37% (mean = 24%)
Total cholesterol	No change unless is very prolonged	No change if bodyweight and diet do not change
LDL-cholesterol	No change	No change if bodyweight and diet do not change
HDL-cholesterol	Increases of 4–18% (mean = 10%)	Increases of 4–18% (mean = 8%)
Lipoprotein (a)	No change	No change

Source: Durstine *et al.* (2002).

greater reductions are seen when baseline levels of triglyceride are high. Exercise lasting >1 hour or meeting a certain energy expenditure produces no change immediately, but can decrease triglyceride levels 24 hours after the exercise session.

High density lipoprotein (HDL) cholesterol is generally responsive to aerobic exercise and increases in a dose-dependent manner with increased energy expenditure. Short duration and low intensity exercise periods can increase HDL, but not always. Longer, more prolonged exercise is likely to be necessary for HDL changes to occur immediately after and the day following exercise. Usually, 12 weeks of exercise training is needed to induce an increase in HDL-cholesterol concentration. Thresholds established from cross-sectional and longitudinal exercise training studies indicate that 15–20 miles/week of brisk walking or jogging, which elicit 1200–2200 kcal of energy expenditure per week, is associated with triglyceride reductions of 5–38 mg/dl and HDL-cholesterol increases of 2–8 mg/dl.

Exercise training seldom alters cholesterol and low density lipoprotein (LDL) cholesterol unless changes in bodyweight and dietary fat reduction are also achieved from the intervention. For LDL-cholesterol overall, there is insufficient evidence to support a decrease in response to exercise training.

Lipoprotein (a) is an LDL subfraction containing apo (a). Lipoprotein (a) concentrations greater than 30 mg/dl have the same harmful coronary artery disease effects as LDL-cholesterol. It is thought that lipoprotein (a) concentration is an inherited trait primarily and does not appear to change following physical activity.

4.6 Insulin sensitivity

There is substantial evidence that physical activity is an effective method of enhancing insulin sensitivity and therefore counteracting insulin resistance (Hardman & Stensel 2003). Insulin sensitivity is defined in terms of the concentration of insulin required to cause 50% of its maximal effect on glucose transport. First, the muscle contractions associated with physical activity activate glucose transport, and this initial process is independent of insulin. As the acute effect of exercise on glucose transport wears off, it is replaced by an increase in insulin sensitivity (Holloszy 2005). In addition, insulin sensitivity is improved by the enhanced ability to synthesise glycogen as a result of the depletion of muscle glycogen following exercise (Holloszy 2005), and increased translocation of the muscle glucose transporter (GLUT-4) to cell surfaces which is stimulated by contracting muscle (Mayer-Davis *et al.* 1998).

Studies have generally suggested improvements in insulin sensitivity following exercise training programmes ranging from 10% to 65%, but improvements in fasting insulin tend to be no longer present 72 hours after an exercise period (Boulé *et al.* 2005). This suggests that improvements in insulin sensitivity and glucose tolerance are short lived and often return to baseline levels 60–72 hours after the last exercise session. Therefore, to maximise improvements in insulin sensitivity in the long-term it is important for exercise episodes to be regular. It is thought that those with the lowest glucose tolerance would gain the most benefit from such exercise programmes (Boulé *et al.* 2005).

Houmard *et al.* (2004) investigated the effects of the amount and intensity of exercise training on insulin sensitivity. Although physical activity encompassing a wide range of intensity and volume minimised insulin resistance, duration of physical activity was shown to be particularly important. An exercise prescription that incorporated approximately 170 minutes of exercise per week improved insulin sensitivity more substantially than a programme utilising approximately 115 minutes per week, regardless of intensity and volume. Compelling evidence from the Insulin Resistance Atherosclerosis Study (Mayer-Davis *et al.* 1998) showed that insulin sensitivity was much greater in subjects who participated in vigorous activity five or more times per week compared with those who rarely or never participated in

vigorous activity. In terms of physical activity intensity, however, this study concluded that higher insulin sensitivity resulted from both greater vigorous and non-vigorous activities.

4.7 Immune response

Physical exertion has both positive and negative effects on the immune response, depending on the intensity and workload of the activity. Evidence from randomised controlled trials and epidemiological studies supports the view that near-daily physical activity reduces the number of days sickness, and also suggests that risk of upper respiratory tract infection (URTI) is reduced in people who engage in regular vigorous physical activity (Nieman 2003). Nieman (2003) proposes that stress hormones, which can suppress immunity, and pro- and anti-inflammatory cytokines, indicative of intense metabolic activity, are not elevated during moderate physical activity. It is thought that although the immune system returns to pre-exercise levels rather quickly at the end of a session, each session is thought to boost immune surveillance, thus reducing risk of infection in the long-term. Similarly, Shephard and Shek (1994) reported that moderate endurance exercise causes either no change or an enhancement of a number of immunological indices such as T-cell count and serum immunoglobulin (antibody) levels.

However, exhaustive exercise tends to lead to adverse changes in several immunological indices, particularly if the activity is accompanied by environmental or competitive stress (Shephard & Shek 1994). This can lead to an increase in the risk of URTIs, especially in athletes who take part in competitive endurance events or who overtrain. Nieman (2003) has described the theory of an open window of altered immunity that occurs immediately after heavy physical exertion. Many components of the immune system exhibit adverse changes after prolonged heavy exertion lasting longer than 90 minutes, and these changes occur in several compartments of the body *i.e.* skin, upper respiratory tract, lung, blood and muscle; most of these changes reflect physiologic stress and immunosuppression. It is thought that an 'open window' of impaired immunity occurs between 3 and 72 hours after exertion where viruses and bacteria may gain a foothold, increasing the risk of infection, particularly of the upper respiratory tract.

4.8 Neurological and psychological effects

Dishman *et al*. (2006) have described some of the neurological responses to increases in physical activity.

Long-term physical activity increases the expression of brain growth factors, and may also have neurogenerative and neuroprotective influences on the brain by stimulating the growth and development of new cells, and protecting against ischaemic neuronal and neurotoxic damage. Long-term physical activity also attenuates neural responses to stress in brain circuits, and so limits sympathetic nervous system responses to stress.

Physical activity also causes the release of endorphins (endogenous opioids) in the brain, which may lead to a sensation of calm and improved mood after exercise (Peluso & Guerra de Andrade 2005). Some opioid receptor blockers have been shown to reduce the effects of exercise, thereby supporting a role for endorphins, but the evidence is equivocal (Peluso & Guerra de Andrade 2005).

It has been proposed that physical activity affects the function of various signalling molecules, known as neurotransmitters, and so can increase vigour and reduce anxiety and tension (Casper 2005). Animal and human studies support increases in brain central serotonin synthesis and metabolism with acute exercise but the extent to which this is a trigger for improved mood is unknown (Fox 1999). Physical activity also increases the synaptic transmission of monoamines which supposedly function in the same manner as anti-depressive drugs; although plausibly this view may be too simplistic (Peluso & Guerra de Andrade 2005).

It is also thought that motor skill training and regular exercise enhance executive functions of cognition and some types of learning, including motor learning in the spinal cord (Dishman *et al*. 2006). In addition, the increase in body temperature associated with activity is postulated to increase relaxation and improve mood (Fox 1999). Physical activity associated increases in cerebral blood flow have also been suggested to be involved.

The effect of physical activity on the mental state also involves psychological mechanisms, and these largely relate to how an increase in physical activity is incorporated into the lifestyle. Physical activity can often be a distraction from daily stresses and anxiety (Casper 2005; Peluso & Guerra de Andrade 2005) and can improve social interaction, which is related to self-esteem (Fox 1999; Peluso & Guerra de Andrade 2005). An increase in self-efficacy is proposed as an important mechanism by Fox (1999) and Peluso and Guerra de Andrade (2005). As physical activity can be seen as a challenging activity, the ability to get involved in it in a regular manner can lead to a sense of achievement. Improvements in perceptions of body image associated with physical activity are also likely to be involved.

Key points

• The total effects of physical activity on total energy expenditure go beyond the physical activity-induced energy expenditure alone. Increases to resting metabolic rate and non-exercise activity thermogenesis are also seen.

• In the long-term, physical activity can increase resting metabolic rate by increasing lean body mass.

• There is also an increase in resting metabolic rate, termed the excess post-exercise oxygen consumption which is detected immediately after exercise.

• Inconsistency in results from studies investigating the effects of physical activity on resting metabolic rate is likely to be the result of whether or not studies continue sufficiently beyond the exercise period.

• The non-exercise activity thermogenesis component of total energy expenditure is likely to increase as a result of physical activity because as people get fitter and lose weight, they increase their level of minor movements e.g. walking around a room at home or the workplace.

• Physical activity can modify body composition favourably by decreasing fat mass, and this can be achieved even if bodyweight remains unchanged.

• There is some inconsistency in epidemiological study results regarding the effects of physical activity on body composition, *e.g.* unexplained gender differences. This is likely to be due to methodological difficulties and/or the simultaneous effects of energy intake.

• In those who are physically active, the greater energy intake needed to match energy expenditure means that it is easier to achieve adequate micronutrient intakes.

• In terms of appetite, physical activity tends not to lead to an increase in energy intake in the short-term. However, individuals respond in a variable manner; consequent energy intakes tend to vary according to physiological (*e.g.* decrease in resting metabolic rate due to weight loss) and psychological (*e.g.* motivation for exercise, dietary restraint behaviour) processes.

• Although negative energy balance as a result of an increase in physical activity can be tolerated in the short-term, long-term studies indicate that this cannot continue indefinitely, because the body cannot tolerate long-term weight loss. Eventually, energy intake increases until energy balance is resumed.

• There is no consensus on whether exercise influences macronutrient intake in the short- or long-term.

• Intensity and duration of physical activity affect the utilisation of energy substrates, and the effect continues post exercise. Those who are more active adapt to using fat as an energy substrate more effectively.

• Physical activity can reduce resting blood pressure and increase the capacity to carry blood in the coronary arteries. Beneficial changes also occur in the lining of blood vessels which help direct the appropriate distribution of blood throughout the body.

• Regular physical activity can exert beneficial effects on the body's capacity for forming and breaking down blood clots.

• Aerobic exercise produces favourable changes in plasma lipid profile. In particular, HDL-cholesterol increases by 4–18% and plasma triglycerides decrease by 4–37% with regular exercise.

• Physical activity is known to enhance insulin sensitivity; improvements are seen immediately following exercise and last up to 72 hours.

• Regular physical activity is associated with beneficial changes to the immune system and a lower risk of upper respiratory tract infections. However, exhaustive exercise (*e.g.* competitive endurance events) is linked to immunosuppression.

• There is evidence of beneficial neurological and psychological responses to increases in physical activity.

5 Physical activity in health and disease

5.1 Physical activity, weight gain and obesity

In 2005, the proportion of English men and women classified as obese was 23.1% and 24.8% respectively (The Information Centre, Lifestyle Statistics 2006). Obesity is a major risk factor for several chronic diseases including type 2 diabetes, CVD and some cancers. The direct cost of treating obesity in 2002 was estimated at £45.8–49.0 million, and this increased to £945–1075 million when the indirect costs of obesity were included (The Information Centre, Lifestyle Statistics 2006). As an increase in physical activity increases overall energy expenditure (see Section 4.1), and thus can contribute towards maintaining energy balance, it is not surprising that physical inactivity has been linked to an increased risk of weight gain and obesity. Indeed, many reports (WHO 2003; Department of Health 2004) have linked the rising obesity epidemic to increasingly sedentary lifestyles. The decrease in energy intake that has taken place alongside the increase in prevalence of obesity (Foster & Lunn 2007) lends further support to this concept.

5.1.1 Observational studies of physical activity and weight change

Fogelholm and Kukkonene-Harjula (2000) conducted a systematic review to investigate the effects of physical

activity on weight gain. Sixteen prospective studies were identified and results were consistent. Greater physical activity was associated with less weight gain, if the level of activity was assessed at the end of the follow-up period, or as a change from baseline to follow-up. This was seen both in subjects who had and had not previously lost weight. But the association between baseline physical activity and later weight change was uncertain. The prospective observational studies suggested that an increase in PAEE of approximately 6300–8400 kJ/week (1500–2000 kcal/week) was associated with improved weight maintenance.

Since the Fogelholm and Kukkonene-Harjula (2000) review was published, Wareham *et al.* (2005) have identified another 14 observational studies on physical activity and weight gain, conducted in adults. Twelve of these studies used self-reported measures of physical activity. Of these studies, only two failed to find an association, whereas nine reported a statistically significant inverse association between physical activity and weight gain. The remaining study showed a reverse association, suggesting that higher baseline BMI predicts future low levels of physical activity (Petersen *et al.* 2004). Different results were observed in the two studies that measured physical activity objectively. First, Tataranni *et al.* (2003) reported that physical activity was not related to change in bodyweight and Ekelund *et al.* (2005b) showed a small inverse association between baseline PAEE and increase in fat mass in younger, but not older, adults.

So overall, more recent studies identified by Wareham (2005) offer more support for a preventive role for physical activity on weight gain; this may be because more recent studies are larger and have more statistical power to detect associations, or because they are better designed and handle confounding more effectively. It is also possible that studies that report an inverse association between physical activity and weight gain are more likely to be published. Overall, the magnitude of the effect was small in the studies reviewed. For example, Koh-Banerjee *et al.* (2003) reported that more vigorous physical activity (25 MET hours/week) is associated with a reduction in waist circumference of 19 mm in men after a nine year follow-up.

Molnar & Livingstone (2000) reviewed similar observational studies conducted in children and adolescents. Overall, the results were inconsistent. Of the seven studies included, four reported that physical activity is associated with less weight gain in children, where the other studies did not observe an association. Methods used for measuring physical activity (subjective *vs.* objective) did not explain the inconsistency in results. Again, the magnitude of associations tended to be small.

For example, Berkey *et al.* (2003) have shown that an increase of one hour in daily recreational physical activity is associated with a 0.06 kg/m^2 decrease in BMI in girls after one year. Similarly, results from the European Youth Heart Study showed that the accumulated amount of time spent performing moderate and vigorous physical activity is related to body fatness in children, but the relationship is weak; the explained variance was <1% (Ekelund *et al.* 2004).

5.1.2 Intervention studies on physical activity and weight change

Fogelholm and Kukkonene-Harjula (2000) reviewed the evidence from 22 exercise intervention studies and concluded that the effects of a prescribed exercise programme on weight change are very limited; the effects were nothing more than modest. In addition, Hardeman *et al.* (2000) conducted a systematic review of trials to prevent weight gain. Nine trials were identified but overall they were uncertain in their conclusions, largely because of methodological issues.

Wareham *et al.* (2005) considered six exercise intervention studies conducted in adults, and published since 2000. The interventions tended to be of a high intensity and implemented over a relatively long period of time (12 weeks to 5 years). Overall, some studies showed an increase in bodyweight in the control group and weight stability in the intervention group, whereas others showed a decrease in bodyweight in the intervention group only, or decreases in both study groups.

Wareham *et al.* (2005) also considered 11 intervention studies conducted in children, and published since 2000. Nine of these studies were school-based interventions. Several trials reported positive changes in physical activity levels but did not show significant differences in bodyweight or body composition between the intervention and the control groups at follow-up.

Overall, the evidence from exercise intervention studies is limited. However, it can be difficult to assess evidence from these studies because adherence is never 100%, and, in addition, non-exercising control groups rarely do zero exercise.

5.1.3 The amount of physical activity needed to maintain a healthy weight

The World Health Organization (WHO 2003) has assessed the observational and trial evidence and concluded that there is convincing evidence that regular physical activity decreases risk, and sedentary lifestyles increase the risk of weight gain and obesity. As discussed

in the Fogelholm and Kukkonene-Harjula (2000) review, WHO recognises that studies that measure physical activity only at baseline, and exercise intervention studies, do not provide entirely consistent results. Thus, it is thought that current patterns of physical activity, rather than past physical activity or enrolment in an exercise programme, is most relevant.

A question remains regarding the amount of physical activity that is needed to maintain a healthy weight. It has been hypothesised that there is a threshold of physical activity below which a lean body mass is no longer maintained (Fogelholm & Kukkonene-Harjula 2000; Hill & Wyatt 2005). Saris *et al*. (2003) have suggested that the average daily PAL reached a critical point some time in the 1980s, perhaps as a result of the telecoms/computer revolution, and at this point substantial numbers of individuals were not able to regulate energy balance and began to store the excess calories as fat, thus leading to an increase in the prevalence of obesity. The critical PAL is uncertain but Di Pietro *et al*. (2004) have estimated from epidemiological data, that a PAL of 1.46–1.60 is required for the prevention of weight gain.

Although there is some uncertainty around the amount of physical activity needed to prevent weight gain, it is probably significantly greater than the amount of physical activity that is needed for the prevention of chronic disease. It is likely that the amount of physical activity required to prevent weight gain varies between populations, and between life stages of individuals. However, consensus on the amount of physical activity needed to prevent unhealthy weight gain was achieved at the IASO 1st Stock conference (Saris *et al*. 2003); this has been the basis for national and international recommendations since then. This group concluded that, although definitive data are lacking, it seems likely that moderate-intensity physical activity of approximately 45–60 minutes per day or a PAL of 1.7 is required to prevent the transition to overweight or obesity. For children, even more activity time is recommended. Consequently, WHO (2003) and the Department of Health (2004) now recommend 45–60 minutes of moderate-intensity physical activity a day to prevent obesity. WHO (2003) also recommend reducing television viewing times by about 30 minutes a day in children because this is associated with lower BMI.

Considering the relationship between physical activity and weight gain at the population level, Hill *et al*. (2003) estimated that on average an extra 418.4 kJ (100 kcal) per day must be expended to restore energy balance and thus eliminate weight gain in Western populations. High levels of physical activity are needed to achieve this so the public health implications need to be considered. Pro-

found structural and environmental changes that promote more active lifestyles are required (Costanza *et al*. 2007; Fox & Hillsdon 2007) (see Section 6.4).

5.1.4 *The effects of physical activity on maintenance of weight loss*

Although evidence from exercise intervention trials suggests that physical activity is not always significantly effective as an initial means of weight loss, Hill and Wyatt (2005) have proposed that physical activity is crucial for maintenance of weight loss. In some, but not all studies, physical activity appears to favourably alter the composition of weight loss so that a higher proportion of weight loss comes from fat mass and less from fat-free mass. Weight loss itself causes a reduction in TEE (partly because of a drop in the energy cost of weight-bearing physical activity), and so any increase in physical activity that occurs with weight loss serves to counteract this effect. Otherwise, during weight loss, food intake needs to be progressively lowered to maintain negative energy balance. Physical activity serves to counteract this effect, by increasing its direct and indirect effects (such as an increase in lean body mass) on energy expenditure (see Section 4.2). It is also thought that physical activity could be a strong predictor of success in weight loss maintenance because it is a marker for compliance. Those who maintain a high level of physical activity may also be better at maintaining their target energy intake (Hill & Wyatt 2005). In terms of dose, Hill and Wyatt (2005) and Saris *et al*. (2003) have concluded that there is compelling evidence that prevention of weight regain in formerly obese individuals requires 60–90 minutes of moderate-intensity activity or lesser amounts of vigorous physical activity per day.

5.2 Physical activity and type 2 diabetes risk

It is estimated that the prevalence of type 2 diabetes in England is 3.3% for men and 1.5% for women (Department of Health 2004). The cost of type 2 diabetes to the National Health Service is huge, and has been estimated at £5.2 billion a year (Department of Health 2004). As obesity is the major risk factor for type 2 diabetes it is clear that physical activity has a major role to play via the prevention of obesity. In addition, there is substantial evidence that physical activity has an independent protective effect on risk of type 2 diabetes (WHO 2003; Buttriss & Hardman 2005). Prospective studies indicate that physically active people have a 33–50% lower risk of developing type 2 diabetes compared with inactive people (Department of Health 2004). For example, the

Iowa Women's Health Study showed that women who had a high *vs*. low physical activity index had a 42% (95% CI 34–49%) reduced risk of type 2 diabetes (Folsom *et al*. 2000). In a prospective study in men, increases of 500 kcal of energy expenditure in weekly leisure-time physical activity were associated with 6% decreases in the risk of type 2 diabetes (Helmrich *et al*. 1991). In the Alumni Health Study, incidence rates declined as energy expenditure increased. For each 2000 kcal increase in energy expenditure, the risk of type 2 diabetes was reduced by 24% (Helmrich *et al*. 1994). In addition to the prospective evidence, non-randomised and randomised intervention trials also show that physical activity can help to reduce the risk of developing type 2 diabetes (Hardman & Stensel 2003). For example, results from the Diabetes Prevention Program study showed a 46% reduction in diabetes incidence for participants who met the physical activity goal of 150 minutes of moderate-intensity activity per week (Hamman *et al*. 2006).

5.2.1 Physical activity in those at high risk of type 2 diabetes

There is evidence that people at high risk of type 2 diabetes can benefit even further from physical activity. In those at high risk, physical activity can reduce risk by up to 64% (Department of Health 2004). For example, exercise can improve insulin sensitivity and glucose tolerance in those with impaired glucose tolerance (state of pre-diabetes where sugar is not processed properly) (Hardman & Stensel 2003). Two randomised controlled trials (Tuomilehto *et al*. 2001; Diabetes Prevention Program Research Group 2002) each found that lifestyle interventions including 150 minutes per week of physical activity and diet-induced weight loss of 5–7% reduced the risk of progression from impaired glucose tolerance to type 2 diabetes by 58%. In addition, a clustered randomised trial, the Da Qing Study, reported a 46% reduction in diabetes incidence with a similar intervention (Pan *et al*. 1997). As a consequence, the Department of Health (2004) states that early stages of insulin resistance can be reversed by weight loss or increases in physical activity. As previously mentioned, the obese are also at high risk of type 2 diabetes, and a combination of obesity and inactivity leads to a particularly high risk of developing type 2 diabetes (Weinstein *et al*. 2004).

5.2.2 Frequency of physical activity

As mentioned in Section 4.6, the effects of exercise on insulin sensitivity are transient so it is important that exercise is frequent to get the most benefit. The effect of a single bout of aerobic exercise on insulin sensitivity lasts 24–72 hours depending on the duration and intensity of the activity (Boulé *et al*. 2005; Sigal *et al*. 2006). Because the duration of increased insulin sensitivity is generally not >72 hours, it is usually recommended that there should not be more than two consecutive days without aerobic exercise (Sigal *et al*. 2006). However, the effect of resistance exercise training on insulin sensitivity may last somewhat longer because of increases in muscle mass.

5.2.3 Intensity of physical activity

Greater benefits on risk of type 2 diabetes are commonly attributed to higher intensity physical activity and some types may be more effective than others (*e.g.* walking and cycling, though the evidence is not entirely consistent) (Department of Health 2004). In a trial conducted by O'Donovan *et al*. (2005a), the effects of 24 weeks of moderate- or high-intensity exercise on insulin resistance were compared. Results suggested that moderate-intensity exercise is as effective as high-intensity exercise in an intervention of equal energy cost. Yet results reported by Folsom *et al*. (2000) in the Iowa Women's Health Study were slightly lower for vigorous physical activity >4 times per week [RR = 0.46 (95% CI 0.29–0.72)] than for moderate physical activity >4 times per week [RR = 0.51 (95% CI 0.43–0.59)]. However, the effect of vigorous physical activity was reduced and no longer statistically significant when further adjustments for body fatness were added into the analyses.

Some interesting data from Ekelund *et al*. (2007) have added further to this debate. In a cross-sectional study, physical activity (as measured by accelerometry) was examined in relation to a cluster of risk factors (body fatness, adverse lipid profile, high blood pressure and insulin resistance) in overweight individuals with an increased risk of type 2 diabetes. Total body movement had a greater effect on this cluster of risk factors than time engaged in moderate and vigorous physical activity. Therefore, these results support the argument that all body movements that contribute to energy expenditure lead to a lower clustered risk. It could be that an exclusive focus on increasing vigorous physical activity and structured exercise could have counterintuitive consequences because of perceived psychological and environmental barriers (see Section 6). It may be that the accumulated time spent on moderate- and vigorous-intensity physical activity, and particularly total body movement, is more important in relation to metabolic risk factors.

5.2.4 Overall evidence and recommendations

The evidence that physical activity is effective in reducing the risk of type 2 diabetes has been summarised by WHO (2003), which concluded that there is convincing evidence that physical activity decreases the risk and physical inactivity increases risk of type 2 diabetes. To decrease risk, WHO recommended practising an endurance activity at a moderate or greater level of intensity (*e.g.* brisk walking) for one hour or more per day on most days of the week. Vigorous exercise (*e.g.* intensity of 80–90% of age predicted maximum HR for at least 20 minutes, at least five times per week) has the potential to substantially enhance insulin sensitivity further.

Disease-specific guidance is also provided by the American Diabetes Association (Sigal *et al*. 2006). In people with impaired glucose tolerance, a programme of weight control is recommended, including at least 150 minutes per week of moderate to vigorous-intensity physical activity.

This level of activity should also improve glycaemic control more generally. In terms of frequency, the physical activity should be distributed over at least three days per week and with no more than two consecutive days without physical activity.

The current UK recommendations advise that 30 minutes of moderate-intensity physical activity five times a week is sufficient to reduce the risk of type 2 diabetes (Department of Health 2004), but because obesity is a major risk factor for type 2 diabetes risk, the recommendation for weight maintenance is also relevant. Therefore, 45–60 minutes of moderate-intensity physical activity per day might provide added benefits, through maintenance of a healthy bodyweight.

For a description of the mechanisms by which physical activity influences insulin sensitivity and thus risk of type 2 diabetes, see Section 4.6.

5.3 Physical activity and cardiovascular disease risk

Cardiovascular disease is the greatest cause of morbidity and mortality in England and leads to over 200 000 deaths per year. The UK government has made CVD a priority in the National Health Service because it is common, can be fatal and can be largely preventable (Department of Health 2004).

A protective role for physical activity on risk of CVD was first identified in studies of occupational physical activity by Morris *et al*. (1953). Morris *et al*. (1953) compared the number of heart attacks experienced by bus drivers, who were seated many hours during the working day, to that of bus conductors, who were much more active during a working day. The conductors experienced roughly half the number of heart attacks and 'sudden deaths' due to heart attack as the drivers.

Since then a growing body of evidence has confirmed that physical activity reduces the risk of a range of cardiovascular outcomes such as coronary heart disease (CHD), coronary artery disease, hypertension and also stroke. Indeed, in its review on risk factors for chronic disease, WHO (2003) concluded that there is convincing evidence that regular physical activity decreases the risk of developing CVD, especially CHD. WHO also considered that 30 minutes of moderate-intensity physical activity on most days of the week is sufficient to achieve beneficial effects on risk of CVD, though a higher volume of activity would have a greater effect. Furthermore, Kohl (2001) has demonstrated that CVD incidence and mortality, and specifically ischaemic heart disease, are causally related to physical activity in an inverse, dose-dependent fashion. However, there was no strong evidence for a dose–response relationship between physical activity and stroke.

A good review of the evidence to support a role for physical activity on CVD prevention is provided by Buttriss and Hardman (2005). This review concludes that physical activity is a major independent protective factor against CHD in men and women, and that unfit and inactive people have double the risk. Benefits were evident in both primary and secondary prevention. Evidence from cohort studies shows that physical inactivity is associated with an increased risk of developing hypertension among both men and women. Intervention trials provide evidence that moderate-intensity activity may achieve a similar, or an even greater blood pressure lowering effect than vigorous-intensity activity. Buttriss and Hardman (2005) indicate that the picture for stroke is less clear, but suggest that there is some evidence that physical activity has beneficial effects on stroke. The Nurses' Health Study has shown physical activity to be associated with a substantial fall in risk of both total and ischaemic stroke in a dose-dependent manner (Hu *et al*. 2000). More recent evidence provided by the EPIC-Norfolk study (Myint *et al*. 2006) also supports a protective role for physical activity in reducing the risk of stroke. In this prospective study, men and women (aged 40–79 years) who were physically active were less likely to have a stroke (RR = 0.70, 95% CI 0.49–0.99) compared with those who were inactive.

5.3.1 Cardiovascular risk factors

Overall, Buttriss and Hardman (2005) concluded that the exercise literature indicates that increased physical activity reduces CVD risk. They also concluded that

more intense exercise, carried out more often and for longer episodes over a more prolonged period of months reduces CVD risk more than less intense exercise. There is evidence to support a variety of mechanisms by which physical activity exerts a beneficial effect on CVD risk. Increases in physical activity may contribute to improvements in a number of cardiovascular risk factors, including body fatness, blood pressure level, blood lipids, endothelial function, coagulation and haemostasis. The evidence to support changes in these risk factors as a result of physical activity is presented in Table 9.

It is well established that the risk factors described in Table 9 contribute towards cardiovascular risk. In addition, there is now increasing evidence that low-grade systemic inflammation contributes to CVD risk. The acute phase reactant, C-reactive protein has been used as an inflammatory marker, and is a predictor of cardiovascular events (Danesh *et al.* 2004). For example, physically active subjects in the EPIC-Norfolk cohort had a 36–52% lower risk of CHD, and this was partly mediated by C-reactive protein (Boekholdt *et al.* 2006). Therefore, reduced systemic inflammation may be another mechanism through which physical activity leads to reduced CVD risk.

5.3.2 Intensity of physical activity

Although it is well established that physical activity can reduce the risk of CVD, it is important to investigate whether specific types or intensities of activity are required to achieve benefits, so that public health messages can be as effective as possible. As discussed, a dose–response relationship between physical activity and CVD risk is evident, but many authors have suggested that activity does not need to be vigorous to exert benefits (Haennel & Lemire 2002; Bassuk & Manson 2003; Buttriss & Hardman 2005; Khaw *et al.* 2006). Bassuk and Manson (2003) indicate that epidemiologic evidence suggests that as little as 30 minutes per day of moderate-intensity physical activity, including brisk walking, reduces the incidence of clinical cardiovascular events in men and women. Although the minimal effective dose is unclear, Haennel and Lemire (2002) have suggested that physical activity that results in energy expenditure of approximately 4200 kJ per week appears to be associated with substantial benefits. This translates to moderate-intensity activity, such as brisk walking, for 30–60 minutes a day, most days of the week. Most importantly, it appears that a regular pattern of physical activity must be maintained to sustain the physiological changes that are responsible for the health benefits (Buttriss & Hardman 2005).

However, there are some studies that indicate that high-intensity physical activity confers greater cardiovascular benefits. For example, in a study by O'Donovan *et al.* (2005b), the effectiveness of 24-week moderate- and high-intensity exercise programmes of equal energy cost were compared. The analysis showed that total cholesterol, LDL-cholesterol, non-HDL-cholesterol and fibrinogen concentrations changed favourably across control, moderate- and high-intensity activities. However, significant changes in total, LDL and non-HDL-cholesterol were only observed in the high-intensity group, which suggests that high-intensity training is more effective in improving cardiovascular risk factors than moderate-intensity training.

It is thought that because vigorous physical activity has been shown to increase aerobic fitness more effectively than moderate physical activity, vigorous physical activity might also have greater effects on CVD risk. To investigate further whether moderate- or high-intensity physical activity is necessary to reduce CVD risk, Swain and Franklin (2006) completed a review of the cardioprotective benefits of vigorous- *vs.* moderate-intensity aerobic exercise. Epidemiological studies identified in this review consistently found a greater reduction in risk of CVD with vigorous physical activity (typically 6 METs or more) than with moderate-intensity physical activity, and reported more favourable risk profiles for individuals engaged in vigorous, as opposed to, moderate-intensity physical activity. Not one single epidemiological study reported greater benefits for moderate rather than vigorous-intensity physical activity. Evidence from clinical trials also supported a crucial role for high-intensity physical activity. Greater improvements in diastolic blood pressure, glucose control and aerobic capacity were seen with vigorous physical activity, but there appeared to be no intensity effect on improvements in systolic blood pressure, lipid profile or body fat loss. Overall, if the TEE of exercise was held constant, exercise performed at a vigorous intensity conferred greater cardioprotective effects than physical activity performed at a moderate intensity.

Measuring intensity of physical activity in epidemiological studies is difficult because the intensity of an activity experienced by any individual is relative to their fitness. For example, brisk walking will be more intensive an activity for someone who is sedentary and less fit than a fit physically active person. Nevertheless, from the available data, it appears that although an accumulation of moderate-intensity physical activity on a regular basis is sufficient to provide cardiovascular benefit, there is evidence to suggest that exercise of a more vigorous nature is even more beneficial. Why vig-

Table 9 Summary of influences of physical activity on risk factors for cardiovascular disease (adapted from Buttriss and Hardman 2005)

Risk factor	Evidence from observational studies	Findings of intervention studies	Comments
Body fatness; amount and distribution	• Cross-sectional studies report lower weight, BMI or skinfold thicknesses among people with higher levels of physical activity or fitness. • Prospective studies less consistent; some show inverse association between amount of leisure-time physical activity and later weight gain, others do not. • Several large cross-sectional studies report an inverse association between energy expenditure from physical activity and indicators of central body fat distribution.	• Reviews and meta-analyses conclude that physical activity promotes fat loss, while preserving or increasing lean mass. • Modest rate of weight or fat loss is positively related, in a dose-response manner, to the energy expended in activity. • Combination of increased physical activity and energy intake restriction is more effective for long-term weight regulation than dieting alone.	• Findings from RCTs differ according to duration of intervention: short-term trials (≤16 weeks) report higher energy expenditures (~9.2 MJ/week) and loss of weight and fat (averages 0.26 kg/week and 0.25 kg/wk, respectively) than trials ≥26 weeks (expenditures ~4.6 MJ/week; weight/fat loss 0.06 kg/week). (For more information, see: Williamson *et al.* 1993; Haapanen *et al.* 1997; Di Pietro 1999; Ross & Janssen 2001; Department of Health 2004)
Blood pressure	• Several cohort studies (men and women) show that physical inactivity is associated with increased risk of later developing hypertension. • Least active have 30% greater risk of becoming hypertensive than most active.	• Findings based on meta-analyses of RCTs show that aerobic exercise decreases systolic and diastolic blood pressure by 3–6 mmHg. • Some evidence that moderate-intensity exercise (40–50% maximal oxygen uptake) is at least as effective as vigorous.	• Single episode of exercise lowers blood pressure for some hours. (For more information, see: Arroll & Beaglehole 1992; Arroll *et al.* 1994; Kelley & McClellan 1994; Hu *et al.* 2000; Fagard 2001; Department of Health 2004)
Blood lipids	• Endurance athletes have 20–30% higher HDL-cholesterol than sedentary peers. • Endurance athletes often (not invariably) have ↓ LDL-cholesterol and ↓ triglycerides.	Intervention studies reveal: • ↑ HDL-cholesterol, average 5%. • Small, usually non-significant changes in total cholesterol. • LDL-cholesterol ↓, average 5 % (inconsistent). • Triglycerides ↓, average 3.5 % (inconsistent).	• Findings of intervention studies inconsistent. • Most consistent change is ↑ HDL-cholesterol found in approximately half of more than 60 intervention studies. No influence of age or sex. • Sizeable weight loss through physical activity enhances favourable effects. • Exercise attenuates the ↓ HDL-cholesterol that accompanies substitution of dietary fat with carbohydrate. • Single episode of exercise reduces triglycerides. (For more information, see: Durstine & Haskell 1994; Leon & Sanchez 2001; Department of Health 2004)
Coagulation and haemostasis	• Cross-sectional studies consistently show that an episode of exercise acutely stimulates fibrinolytic activity.	• Evidence inconsistent on changes in fibrinogen and markers of fibrinolytic activity (tPA, PAI-I). • Some evidence that training at moderate intensity decreases platelet adhesion and aggregation.	• An episode of strenuous exercise activates platelets in sedentary but not in physically active, healthy subjects. • By contrast, an episode of moderate exercise (50–55% maximal oxygen uptake) has an inhibitory effect on platelet adhesion and aggregation. (For more information, see: Rauramaa *et al.* 2001)
Endothelial function		• One small RCT found that exercise training improves endothelium-dependent vasodilation of coronary arteries.	• Animal studies show that training increases the interior diameter of major coronary arteries, increasing maximal coronary blood flow. (For more information, see: US Department of Health and Human Services 1996).

BMI, body mass index; HDL, high density lipoprotein; LDL, low density lipoprotein; PAI-I, plasminogen activator inhibitor-I; RCT, randomised controlled trial; tPA, plasminogen activator.

orous activity should be more effective is, as yet, unclear, but we know it is better at increasing aerobic capacity.

5.3.3 Type of physical activity

Tanasescu *et al.* (2002) have considered exercise type in relation to CHD risk in a large cohort of men. Total physical activity, running, weight training and rowing were each inversely associated with CVD risk. Men who ran for an hour or more per week had a 42% risk reduction (RR = 0.58, 95% CI 0.44–0.77) compared with men who did not run. Men who trained with weights for 30 minutes or more per week had a 23% risk reduction (RR = 0.77, 95% CI 0.61–0.98) compared with men who did not train with weights. Rowing for one hour or more per week was associated with an 18% risk reduction (RR = 0.82, 95% CI 68–0.99).

A number of studies have specifically investigated the effects of walking on CVD risk. Oguma and Shinoda-Tagawa (2004) reviewed 30 studies that measured physical activity in women and concluded that absolute walking amount (from as little as one hour per week) was associated with a reduced risk of CVD.

Active commuting by walking or cycling, and risk of CVD was reviewed in a meta-analysis by Hamer and Chida (2007). A robust protective effect of active commuting on CVD outcomes (RR = 0.89, 95% CI 0.81–0.98) was demonstrated. The effects, however, were more robust in women (RR = 0.87, 95% CI 0.77–0.98) than men (RR = 0.91, 95% CI 0.80–1.04). Although these results may suggest some disparity with those that indicate that high-intensity physical activity is needed to reduce CVD risk, there is also some prospective evidence that greater walking pace is important for CVD benefits, independently of total walking hours (Manson *et al.* 1999). Overall, these findings have important public health implications because active transport such as cycling and walking to work is a feasible method of integrating regular physical activity into increasingly sedentary lifestyles.

To encourage uptake of physical activity, it is often reported that accumulated short bouts of activity are effective in reducing CVD risk. A number of studies have demonstrated that accumulated bouts of short duration physical activity are effective. For example, Park *et al.* (2006) reported that four 10 minute bouts of walking were more effective in lowering daytime ambulatory blood pressure than a continuous 40 minute session in pre-hypertensive adults. However, the available data to support the effectiveness of accumulated physical activity is not totally consistent (Buttriss & Hardman 2005).

5.4 Physical activity and cancer risk

In England, over 220 000 people are diagnosed with cancer and more than 120 000 die from cancer each year (Department of Health 2004). It is estimated that, in Western societies, one in three people will develop cancer in their lifetime. Yet many cancers are linked to lifestyle factors such as smoking, alcohol consumption, diet and obesity so potentially are preventable (WCRF/AICR 1997).

Over the last 10–15 years attention has been drawn to a potential relationship between physical activity and cancer risk. In 2002, the International Agency for Research on Cancer (IARC) published Volume 6 of its handbooks of cancer prevention *Weight Control and Physical Activity*. It concluded that epidemiological studies, animal experiments and mechanistic investigations all support a beneficial effect of weight control and physical activity in the prevention of cancer; regular physical activity reduces the risk of breast and colon cancers, and possibly reduces the risk of endometrial and prostate cancers. Miles (2007) has recently reviewed the research on physical activity and cancer prevention, published since the IARC report, focusing on evidence from reviews and cohort studies. The results of these two reviews are summarised in this section.

5.4.1 Colon cancer

The epidemiological results (from 20 cohort and 22 case–control studies) reviewed by IARC (2002) showed high levels of physical activity to be consistently associated with reduced risk of colon cancer. The magnitude of decreased risk was around 40%. The amount of activity to reduce risk was not clear given the variety of methods used to assess physical activity, but it was estimated that 30–60 minutes per day of more intense types of activities are needed to have the greatest effect on colon cancer risk. Long-term physical activity also appeared to be an important modifier of risk. However, when physical activity was assessed by occupation, there was some inconsistency in results. Overall, the IARC working group concluded that there was sufficient evidence from human studies to support a preventive effect of physical activity on colon cancer.

In the recent review by Miles (2007), the evidence for the role of physical activity in colon cancer prevention was compelling. Miles (2007) reported consistency across four good quality cohort studies and a dose–

response effect has been reported (Friedenreich *et al*. 2006). Furthermore, a stronger relationship between physical activity and colon cancer was observed in men. Although it might be feasible that there is a true difference in the metabolic response to physical activity between men and women, this feature of the evidence might be a result of the greater methodological challenges of measuring physical activity in women. Household activity may be of particular significance in women and has been included in few analyses of physical activity and colon cancer risk to date.

A number of mechanisms have been proposed to explain the association between physical activity and reduced risk of colon cancer. Samad *et al*. (2005) suggested that possible mechanisms might involve hyperinsulinemia, obesity, decreased gut transit time, change in prostaglandin ratio, lowered bile acid secretion and altered gut flora.

5.4.2 Breast cancer

IARC (2002) reviewed 14 separate cohort studies that investigated the relationship between physical activity and breast cancer risk; eight of these observed an inverse association. Five found reductions in risk associated with occupational physical activity and four found reductions in risk with recreational physical activity. It was calculated that a total of 30–60 minutes of moderate to vigorous-intensity physical activity is needed for breast cancer reduction. The IARC working group concluded that there was sufficient evidence for a breast cancer preventive effect from physical activity.

A review of physical activity in adolescent and young women (Lagerros *et al*. 2004) suggests that this period of the lifespan is particularly important for breast cancer risk. However, there is potentially a strong correlation between physical activity in adolescence/young adulthood and physical activity later in adulthood, so the observed association may be a reflection of lifetime exposure to physical activity rather than the result of physical activity at a specific time point. It is also interesting that of the studies reviewed by IARC (2002), the strongest association was seen in the studies that measured physical activity sustained over a lifetime (Verloop *et al*. 2000; Friedenreich *et al*. 2001); but substantial risk decreases were also observed in studies of activity performed earlier in life (age <40 years).

The results from the available reviews are supported by the 11 cohort studies investigating the relationship between physical activity and breast cancer published since 2002 (Miles 2007). There was consistency across several prospective studies, several good quality studies

have reported an inverse association and a dose–response effect has been found (Miles 2007). By considering these results by menopausal status, it is clear that the decrease in risk is stronger in post-menopausal women, and there is evidence that oestrogen receptor-positive/progesterone receptor-negative tumours are most sensitive to the changes in risk as a result of physical activity. This latter observation lends support to changes in oestrogenic processes as the underlying mechanism for the observed associations, particularly as high lifetime exposure to oestrogen is known to be a risk factor for breast cancer.

As obesity is a risk factor for post-menopausal but not pre-menopausal breast cancer, another important mechanism by which physical activity modifies risk is likely to be via changes in adiposity. It is possible that physical activity can lead to reduced levels of circulating oestrogen through decreasing levels of body fat because adrenal androgens are converted to oestrogens in adipocytes (Hardman 2001).

5.4.3 Endometrial cancer

The results from three cohort and seven case–control studies reviewed in the IARC (2002) report suggested a 20–40% decreased risk of endometrial cancer for those women with the highest physical activity levels. Overall, however, the IARC working group concluded that there was limited evidence to support a preventive effect for physical activity on endometrial cancer.

Miles (2007) identified four prospective studies, published since 2002, that investigated the relationship between physical activity and endometrial cancer risk. The majority of these studies showed some suggestion of a decreased risk of endometrial cancer with increasing physical activity, but there was some inconsistency in the results whereby only daily, moderate, occupational physical activity or sedentary behaviour had a statistically significant effect on risk, but other subsets of physical activity showed no association. The strongest associations were reported by Schouten *et al*. (2004), and these were not adjusted for BMI. It is therefore possible that some of this decrease in risk is attributable to differences in subjects' adiposity.

Obesity is known to be a risk factor for endometrial cancer, and physical activity may exert its effects through decreasing body fatness. Prevalence of diabetes mellitus is also positively associated with endometrial cancer (Westerlind 2003), and it is thought that chronic hyperinsulinaemia may be a cause of cancer of the endometrium, via its effects on sex steroids and their binding proteins (Kaaks & Lukanova 2001).

5.4.4 Prostate cancer

IARC (2002) identified reports from eight cohort studies: six showed no association between physical activity and risk of prostate cancer, but two cohort studies showed a weak inverse association. Some of the null studies did, however, report inverse associations in subgroups of the cohorts. Overall, IARC (2002) concluded that there is limited evidence to support a role for physical activity in prostate cancer prevention.

A major limitation to prostate cancer epidemiology is the knowledge that prostate cancer becomes more common with age and in many cases remains asymptomatic and is effectively biologically insignificant. Recently, studies have been able to focus on advanced prostate cancers and this carries with it some major advantages, in the light of increasing screening programmes for prostate-specific antigens which allow the detection of pre-clinical stages of prostate cancer. Miles (2007) recently identified an additional review and six cohort studies published from 2002 to 2006. Three out of six reported a significantly decreased risk of advanced cancer with more physical activity. It is possible that the remaining studies did not accrue enough advanced prostate cancer cases to have sufficient statistical power to detect associations.

Currently, the inconsistency between studies leads to some conservatism regarding the strength of the relationship between physical activity and prostate cancer prevention. Although, there is some suggestion of decreased risk with physical activity in a number of prospective studies, more research on advanced prostate cancer is required to ascertain whether the negative results are in the minority, or are perhaps the result of study limitations. Torti and Matheson (2004) have proposed some mechanisms to explain a potential link between physical activity and prostate cancer: alterations in hormones, enhancement of the immune system and generation of reactive oxygen species. However, these are not specific to the prostate.

5.4.5 Lung cancer

IARC (2002) identified five cohort and two case–control studies that reported on the relationship between lung cancer risk and physical activity. A lower risk of lung cancer was seen in all the cohorts. Reductions in risk ranging from 20% to 60% were reported in these studies for both non-occupational and occupational physical activity and an inverse dose–response relationship was also observed. However, there was some concern that these results could be confounded by smoking. Although all the studies reviewed had

adjusted for smoking status in their analyses, smoking could have been associated with other lung diseases among the study subjects or not measured adequately. As a result of this uncertainty, the IARC working group concluded that there is inadequate evidence to support a preventive role for physical activity in lung cancer aetiology.

Miles (2007) identified further evidence from another review (Tardon et al. 2005) and three cohort studies; these all reported an inverse association between physical activity and lung cancer. There was some suggestion that it is the more vigorous activities that modify risk the most, rather than total physical activity. Yet, because smoking is a well-known risk factor for lung cancer, there was again some concern that residual confounding may have influenced the results.

Possible mechanisms by which vigorous physical activity might decrease the risk of lung cancer include reducing the concentration of carcinogenic agents in the airways, and influencing the duration of agent–airway interaction and the amount of particle deposition through increased ventilation and perfusion (IARC 2002). It is also possible that physical activity can enhance endogenous antioxidant defences, and that its influence might be mediated by the effects of physical activity on insulin-like growth factor levels and binding proteins (Steindorf et al. 2006).

The epidemiological evidence on cancers of the colon, breat, lung, endometrium and prostate is summarised in Table 10. Epidemiological research to investigate the potential relationship between physical activity and other types of cancer has been published (particularly cancers of the pancreas and ovary) but this evidence is limited for a number of reasons. Because informative conclusions cannot be drawn for these cancers, the evidence is not presented here.

5.5 Physical activity, bone health and osteoporosis risk

Osteoporosis is a degenerative bone disease that is characterised by low bone mass or low bone mineral density (BMD). Bones become brittle and there is a greater tendency for fractures as a result of minor falls (Department of Health 2004). There are around 60 000 osteoporotic hip fractures in the UK each year, and the health and social care costs of osteoporosis in the UK amount to £1.7–1.8 billion a year.

Physical activity is known to affect risk of osteoporosis via its effects on bone turnover. The greatest effects on bone turnover take place during growth, because the bone matrix is in a dynamic state which allows the bone

Table 10 Summary of evidence on the relationship between physical activity and the prevention of cancer (adapted from Miles 2007)

Cancer site	Conclusion	Comments
Colon	Well-established decreased risk	Relationship stronger in men than women
Breast	Well-established decreased risk	Relationship stronger in post-menopausal than pre-menopausal women
Lung	Consistent evidence of decreased risk	Some concern over residual confounding for smoking
Endometrium	Mostly consistent evidence of decreased risk	Inconsistency in type of activity important for risk and strongest associations not adjusted for body mass index
Prostate	Evidence suggestive of decreased risk	More evidence on relationship with advanced prostate cancer needed

tissue to reorganise and grow to withstand new mechanical tensions and load conditions (Vicente-Rodriguez 2006). Mechanical stimuli on the skeleton include intermittent mechanical stress caused by body movements, and vibrations exerted on the bone by muscle fibre contractions and by other vibrations such as induced by racket sports. Physical activity also exerts metabolic stimuli on the skeleton by increasing blood supply and thus nutrients, hormones and oxygen supply to bones. Furthermore, the rhythmic nature of physical activity amplifies the volume of pulsatile growth hormone delivery, which is essential for cellular proliferation in bone (Borer 2005). Skeletal tissue is responsive to these mechanical and metabolic stimuli, which govern bone turnover. There is a continuous balance between the mechanical drive towards the formation of bone and the metabolic drive towards resorption of bone (Murphy & Carroll 2003), and a remodelling process takes place over 3–4 month periods whereby bones go through stages of resorption, formation and mineralisation (Kohrt *et al.* 2004). Physical activity is unique in that it can activate the bone multicellular unit via both mechanical and metabolic stimuli to promote the retention of bone mass.

In addition to these direct effects on bone, the increase in muscle mass associated with physical activity increases the forces generated on the bones where the muscles attach, so further adding to the mechanical stimuli on the bones (Vicente-Rodriguez 2006).

Most studies that have investigated the effects of physical activity on bone health have measured BMD, which is currently the best surrogate measure of bone strength (Kohrt *et al.* 2004). Clinically, BMD is important because low BMD greatly elevates the risk of fractures with minimal trauma, such as a fall to the floor. It is clear that BMD increases with activity levels. Meta-analyses have indicated that athletes have a 25% greater BMD than generally active people, and active people have a 30% higher BMD compared with inactive people (Branca 1999).

5.5.1 Physical activity in childhood and adolescence

Weight-bearing physical activity has beneficial effects on bone health across the age spectrum. It is generally accepted that maximising the increase in BMD in younger life, and minimising its age and endocrine-associated decline in later years, is a suitable strategy to reduce the risk of osteoporosis and associated fractures (Kohrt *et al.* 2004). There is some evidence that exercise-induced increases in bone mass in children are maintained into adulthood, suggesting that physical activity habits during childhood may have long-lasting effects on bone health. Bone mass increases throughout adolescence and reaches a peak at the end of this period. The peak bone mass (PBM) also reflects skeletal size, and is achieved in early adulthood, a few years after growth in height has ceased. Maximising PBM elevates the starting point from which bone mass declines with age.

It is not necessary to perform a high volume of exercise to achieve the benefits from physical activity, as notable effects on bone may be achieved with just three hours of participation in sports (Vicente-Rodriguez 2006). It has been observed that bone mass (Kohrt *et al.* 2004) and BMD (Tobias *et al.* 2007) are both higher in children who are physically active compared with those who are less active. It is also clear that PBM is higher in children who participate in sports that have high impact forces such as gymnastics or football, rather than low impact activities such as walking or activities that are not weight-bearing such as swimming (Kohrt *et al.* 2004; Vicente-Rodriguez 2006).

Puberty is an important time period during which the effects of physical activity can maximise PBM (Kohrt *et al.* 2004; Borer 2005; Vicente-Rodriguez 2006). Starting physical activity prior to the pubertal growth spurt stimulates both an increase in bone and skeletal muscle size to a greater degree than is observed with normal growth in children who are not physically active. Again, high impact and weight-bearing sports are thought to be most effective; such sports participation

during this growth period seem to increase PBM by 10–20%. Furthermore, it is clear that at least 25% of adult total bone mineral content is attained during a two year period of fast bone mineral accrual during growth (age 11–13 years in girls and 12–14 years in boys). In boys, BMD continues to increase through late adolescence, while in girls BMD ceases to increase earlier (see Vicente-Rodriguez 2006). Based on evidence from multiple small randomised controlled trials, the American College of Sports Medicine has developed an exercise prescription that will augment bone mineral accrual in children and adolescents (Kohrt *et al.* 2004):

• mode: impact activities, such as gymnastics and jumping, and moderate-intensity resistance training, participation in sport that involves running and jumping (likely to be of benefit, but scientific evidence is lacking);
• intensity: high, in terms of bone loading forces; for safety reasons resistance training should be <60% of one repetition maximum;
• frequency: at least 3 days per week;
• duration: 10–20 minutes (two times per day or more may be more effective).

5.5.2 Physical activity in adulthood

During adulthood, the primary goal of physical activity in terms of bone health should be to maintain bone mass. Whether adults can increase BMD through exercise training remains equivocal (Kohrt *et al.* 2004). But observational studies suggest that the age-related decline in BMD is attenuated, and the relative risk for fracture is reduced in people who are physically active, even when the activity is not particularly vigorous. However, there have been no large randomised controlled trials to confirm these observations and there have been no dose–response studies to determine the volume of physical activity required for such benefits (see Kohrt *et al.* 2004). Nevertheless, based on the available evidence from observational studies, the American College of Sports Medicine has developed an exercise prescription that will preserve bone health during adulthood (Kohrt *et al.* 2004):

• mode: weight-bearing endurance activities, activities that involve jumping and resistance exercise;
• intensity: moderate to high, in terms of bone loading forces;
• frequency: weight-bearing endurance activities 3–5 times per week, resistance exercise three times per week;
• duration: 30–60 minutes per day of a combination of weight-bearing endurance activities, activities that involve jumping and resistance exercise that targets all major muscle groups.

The effects of physical activity on bone health are known to differ for post-menopausal women, largely as a result of changes in hormonal status. Oestrogen withdrawal at the menopause results in rapid bone loss that is distinct from the slower age-related bone loss. The bones of post-menopausal women have a limited capacity to adapt to the mechanical stress of exercise. Instead, the effectiveness of exercise on BMD after the menopause depends heavily on adequate availability of dietary calcium (Borer 2005). Interactions between physical activity, calcium and vitamin D status have been studied extensively and Murphy and Carroll (2003) have suggested that physical activity might have a greater effect in calcium replete individuals. It is possible that the lack of evidence to suggest that physical activity prevents bone loss or increases BMD after the menopause may be due to inadequate calcium availability or low-intensity exercise training (Borer 2005). But overall, although physical activity may counteract to some extent the age-related decline in bone mass, there is currently no strong evidence that even vigorous physical activity attenuates the menopause-related loss of bone mineral (Kohrt *et al.* 2004).

After the age of 40 years, bone mass decreases by 0.5% per year (Kohrt *et al.* 2004) and so physical activity is also important in older adults. Meta-analyses have shown that a variety of types of exercise can be effective in preserving bone mass in older women and men (Kohrt *et al.* 2004). The benefits of physical activity in this age group are particularly important because of the propensity for falling, and thus an increased risk of osteoporotic fractures. WHO (2003) has concluded that there is convincing evidence that physical activity decreases the risk of osteoporotic fractures in older people (for men and women older than 50–60 years with a low calcium intake and/or poor vitamin D status). In particular, activity that maintains or increases muscle strength, co-ordination and balance is beneficial in prevention of osteoporotic fractures. By regulating the production and circulation of hormones, improving balance mechanisms and developing muscle power, physical activity can help prevent up to 25% of falls (Department of Health 2004).

Maintaining regular physical activity across the lifespan should be viewed as essential for achieving and maintaining good bone health. Regular lifetime weight-bearing activities, especially in modes that include impacts on bones and are done in a vigorous fashion, increase the PBM achieved in youth and help to maintain bone mass in later life. As the exercise response on bone mass is curvilinear, the greatest gains will be seen in those who have previously been least

active (Murphy & Carroll 2003). Although there is no upper age limit for this guidance, as age increases, so does the need to ensure that physical activity can be performed safely.

5.6 Physical activity, psychological wellbeing and mental health

Mental health problems are prevalent in Britain with at least one in six people suffering at any one time (Department of Health 2004). Clinical depression and mixed anxiety are the most common forms of mental illness and prevalence of these conditions is increasing (Department of Health 2004). The treatment of mental illness in England requires £3.8 billion per year by the National Health Service (Department of Health 2004). Although less well-defined, psychological wellbeing is also discussed in this section. Wellbeing is a complex psychological construct that can be measured by mood, sleep, self-esteem and cognitive function.

5.6.1 Clinical depression

Several reviews (Fox 1999; Biddle *et al*. 2000; Paluska & Schwent 2000; Casper 2005; Larun *et al*. 2006) have concluded that there is good evidence that physical activity can reduce the risk of clinical depression. In particular, Biddle *et al*. (2000) have thoroughly assessed the epidemiological evidence in terms of strength of association, consistency of evidence from different populations and settings, temporality (inactivity takes place before depression), biological plausibility and experimental evidence; overall, these components support the view that inactivity produces a high risk of subsequent depression. Biddle *et al*. (2000) state that the evidence is strong enough to conclude that there is support for a causal link between physical activity and reduced clinically defined depression.

The beneficial effect of physical activity on depression is seen across the lifespan. In a review of 16 randomised controlled trials, Larun *et al*. (2006) reported a small effect of exercise in reducing depression in children and adolescents. However, the clinical diversity of subjects, interventions and methods, has limited the ability to draw firmer conclusions. It appeared that intensity of physical activity made no difference to outcomes. Because the research is so scarce, the effect of physical activity in children who are receiving psychosocial treatment is unknown. Although studies of older adults with depression have been limited, physical activity appears to be beneficial for this age group too (Paluska & Schwent 2000).

5.6.2 Anxiety and stress

Anxiety and stress are complex issues. Physical activity interventions can affect immediate anxiety feelings (state anxiety) or relatively stable anxiety characteristics (trait anxiety), or markers such as blood pressure or HR. There is evidence that physical activity has an important effect on anxiety. Longer-term exercise training can reduce trait anxiety and single exercise sessions can result in reductions in state anxiety (Biddle *et al*. 2000). Beneficial effects appear to equal those achieved via meditation or relaxation (Paluska & Schwent 2000). Biddle *et al*. (2000) have reported that effect sizes seen in meta-analyses are typically low to moderate, but these are derived studies that have used diverse methods and different measures of anxiety and physical activity. Stronger effects are shown in randomised trials (Biddle *et al*. 2000).

Studies of older adults (Paluska & Schwent 2000), children and adolescents (Larun *et al*. 2006) with anxiety have been limited, but physical activity appears beneficial for these age groups. Overall, it appears that physical activity can be used as a means to decrease stress and anxiety on a daily basis.

5.6.3 Psychological wellbeing

There is great variation in the perception of psychological wellbeing; it is a term that is not well defined. Gauvin and Spence (1996) have described psychological wellbeing as a phenomenon that comprises both emotional functioning and satisfaction with life. Mood, self-esteem, sleep and cognitive performance are all often considered important aspects of psychological wellbeing. The lack of a precise definition of psychological wellbeing means that its measurement differs among researchers, and so this is a limitation to research in this area.

In relation to mood and wellbeing, a positive association between physical activity and indices of subjective wellbeing has been reported by large-scale surveys in several countries using different methods and criteria (Fox 1999; Biddle *et al*. 2000). The evidence is fairly consistent across meta-analytic or narrative reviews and these large-scale epidemiological surveys, and points to a convincing relationship between physical activity and improved positive mood (Biddle *et al*. 2000). Furthermore, experimental trials support a positive effect on mood for moderate-intensity exercise; effective benefits are more likely to be experienced if participants focus on personal goals (Fox 1999; Biddle *et al*. 2000).

Additionally, physical activity can improve physical self-esteem. According to a review by Lotan *et al*. (2005), many researchers have established a relationship

between physical activity and self-esteem, self-efficacy and psychological functioning. The positive effects are likely to be greater for those with initially low self-esteem and can be experienced by all age groups, but there is strongest evidence for change in children and middle-aged adults (Biddle *et al.* 2000). The impact of exercise on self-esteem in children and young adults has been reviewed by Ekeland *et al.* (2004). The results from 23 randomised controlled trials indicate that exercise has positive short-term effects on self-esteem in children and young people. However, the studies identified were generally small, heterogeneous and of low quality.

Sleep quality is sometimes associated with psychological wellbeing, and daylight exercise is closely related to sleep quality (Fox 1999). A meta-analysis of 38 studies showed that exercise had no effect on the time it took to fall asleep, but it produced small increases in the amount of sleep and slow wave sleep achieved (Youngstedt *et al.* 1997).

In terms of cognitive performance, studies that have considered reaction time and memory in older people have been reviewed. Cross-sectional data show that fitter, older adults display better cognitive functioning but experimental evidence is equivocal (Fox 1999). Results from intervention studies are inconclusive but findings from meta-analyses indicate a small but significant improvement in cognitive functioning of older adults who experience an increase in aerobic fitness (Biddle *et al.* 2000). Furthermore, there is some evidence from clinical trials that shows exercise can help reduce the risk of dementia and Alzheimer's disease (Lotan *et al.* 2005).

Key points

• Greater physical activity is associated with less weight gain. However, results from epidemiological studies indicate that the magnitude of the effect is small and results from exercise intervention studies are inconsistent.
• Weight loss programmes that include a regular physical activity component are more effective at maintaining weight loss in the longer-term.
• There is a consensus view that 45–60 minutes of moderate-intensity physical activity or a PAL of 1.7 is required to prevent the transition to overweight and obesity.
• There is substantial evidence that physical activity has an independent protective effect of 33–50% on risk of type 2 diabetes. To reduce the risk of type 2 diabetes mellitus it is not clear whether particular types or intensities of physical activity are more effective. However, it

is recognised that resistance training is as effective as aerobic exercise on insulin sensitivity.
• Those who are at a high risk of type 2 diabetes (*e.g.* the obese and those with impaired glucose tolerance) can benefit the most from physical activity.
• Physical activity reduces the risk of a range of cardiovascular outcomes, such as CHD, coronary artery disease, hypertension and stroke. Physical activity exerts its effects via changes in body fatness, blood pressure, blood lipids, the function of the blood vessel linings and blood clotting processes.
• Physical activity affects the risk of CVD in a dose-dependent manner. Benefits are seen with regular moderate-intensity physical activity, *e.g.* walking, but more intense exercise (*e.g.* 6 METs) carried out more often and for longer episodes can decrease risk even further.
• It is well established that physical activity reduces the risk of colon cancer (especially in men) and breast cancer (especially in post-menopausal women).
• There is consistent evidence that physical activity reduces the risk of lung and endometrial cancers. There is also some indication that physical activity can reduce the risk of advanced prostate cancer.
• Physical activity habits in childhood, particularly during growth periods including puberty, have a long-lasting effect on bone health. Weight-bearing and high impact activities are most effective at increasing bone strength.
• In older adults, physical activity is important to counteract the age-related decrease in bone mass. Physical activity can decrease the risk of osteoporotic fractures in older people, particularly if the activity increases muscle strength, balance and co-ordination.
• There is good evidence that physical inactivity increases the risk of clinical depression. There is also good evidence that physical activity has an important beneficial effect on anxiety.
• Physical activity is important for psychological wellbeing and can be used as a means to improve mood and self-esteem. There is also some suggestion that physical activity improves sleep and cognitive function.

6 Physical activity and public health

6.1 Physical activity across the life course

Sections 4 and 5 highlighted the health benefits of physical activity in terms of its physiological effects and its relationship with chronic disease. It is clear that physical activity exerts its benefits throughout the life course. Although children are known to be more active than

adults (see Section 3), the importance of physical activity in childhood is exemplified by the recommendation for greater amounts of physical activity in childhood. Children and young people should achieve a total of at least 60 minutes of at least moderate-intensity physical activity each day (Department of Health 2004). At least twice a week, this should include activities to improve bone health.

Physical activity in childhood is beneficial in terms of increasing social interaction and wellbeing, and it is important for healthy growth and development and maintaining energy balance (Department of Health 2004). Considering the rising prevalence of obesity in UK children (Zaninotto *et al*. 2006), encouraging physical activity is a crucial way of promoting a healthy weight in childhood and adolescence. Section 5.1 discusses the evidence for an association between physical activity and weight gain in children. Furthermore, as obesity is a major risk factor for type 2 diabetes and CVD, physical activity in childhood has an indirect effect on reducing the risk of chronic diseases later in life, via its effects on weight gain. Indeed, the beneficial effects of physical activity on adiposity, insulin sensitivity and other CVD risk factors are seen from childhood onwards. It has been demonstrated that physical activity is associated with beneficial changes in triglycerides, blood pressure, HDL-cholesterol, insulin resistance and adiposity in pre-pubertal and early pubertal children (Brage *et al*. 2004; Ekelund *et al*. 2006) and adolescents (approximately 15 years old) (Bo Andersen *et al*. 2006; Ekelund *et al*. 2006).

It has also been proposed that childhood is a critical time period to be physically active because habits at this age can track into adulthood. Although there is some evidence to support this, tracking of physical activity patterns from childhood to adulthood is only weak to moderate. Nevertheless, it is likely that the way in which exercise and sport is experienced in childhood impacts upon physical activity patterns later in life in terms of attitudes, enjoyment and setting of lifetime habits (Department of Health 2004).

A life course approach to chronic disease epidemiology suggests that periods of growth are particularly important for determining chronic disease risk. The effects of physical activity on bone health and particularly osteoporosis are an excellent example of this. Physical activity has beneficial effects on bone health across the age spectrum. Physical activity in childhood increases bone density and case–control evidence suggests that low bone density is associated with fracture risk in children (Clark *et al*. 2006). Furthermore, optimising PBM in childhood and adolescence can decrease the risk of osteoporosis, and osteoporotic fractures in later life (see *Section 5.5*). For most benefit, physical activity needs to be high impact and weight-bearing, and it is particularly important from early puberty and throughout this growth period. This is largely because the bone matrix is in a dynamic state during growth where bone tissue is able to reorganise in response to mechanical and metabolic stimuli.

After 40 years of age, bone mass decreases by 0.5% per year (Kohrt *et al*. 2004). Physical activity is therefore important in older adults, in order to reduce the age-related decline in bone mass. Physical activity and its strengthening effects on bone are particularly important in older adults because of the propensity for falling, and thus an increase in risk of osteoporotic fractures. In particular, activity that maintains or increases muscle strength, co-ordination and balance is most beneficial. In this way, physical activity can help prevent up to 25% of falls in older people (Department of Health 2004).

There are also age-related declines in the functional capability of the cardiovascular and muscular systems, which can be counteracted by maintaining physical activity into old age. Taylor *et al*. (2004) have described the deterioration of the cardiovascular system that results in reduced cardiac output and an associated reduction in oxygen delivery to tissues. It is evident that apparently healthy individuals experience decreases in functional capacity of the cardiovascular system with ageing. However, the cardiovascular system can adapt to exercise equally well in old and younger populations.

Muscle mass and strength decline with age, and this leads to changes in body composition (a decline in lean body mass) (Hardman & Stensel 2003). Although ageing *per se* is the main cause of muscle loss, this process is accelerated by inactivity. At the age of 60 years, muscle mass is lost at the rate of around 0.5–2% per year but this loss can be reduced by strengthening exercise training, which can have profound effects in reversing muscle wasting and the accompanying functional deficit (Wilkes & Rennie 2008). If greater muscle mass is established earlier in life, there is more to lose as ageing progresses, without the loss substantially affecting function.

Physiological adaptations to exercise can still take place in the older body and we are capable of high levels of physical activity as we age. Benefits are apparent even for men over the age of 60 years who become physically active after years of a sedentary lifestyle (Blair *et al*. 1995), and also in much older men and women. Men aged 80 years and over who were in the highest fitness category had a lower death rate compared with unfit men who were 25 years younger (see Blair 2007). This

demonstrates just how powerful activity and fitness are as protective factors. However, recommending specific amounts of activity for older people remains a contentious issue because of the large variation in the ageing process and the capacity to engage in physical activity because of disabilities (Taylor *et al.* 2004).

Physical activity levels are known to decrease substantially in old age (see Section 3.1), and this is exacerbated in older people who are housebound or, in particular, living in residential care. Substantially fewer older adults in care homes walk for 15 minutes continuously at least once per month at a brisk/fast pace compared with older adults living in private households (Department of Health 2000, 2002).

This decline in physical activity eventually leads to lack of mobility, and a loss of independence and quality of life. Yet there is growing evidence that supports the antidepressant effect of physical activity and its role in improving social, cognitive, emotional and perceived physical function in older adults and also of alleviating physical symptoms (Taylor *et al.* 2004). Consequently, there is a major public health impact of physical inactivity in older adults. In short, maintaining physical activity into old age can counter many of the effects of ageing, and so the recommended amount of physical activity in adulthood should be maintained into old age for as long as possible.

6.2 Current recommendations on physical activity

The current UK recommendations for physical activity were presented in the *At Least Five a Week* report from the Chief Medical Officer (Department of Health 2004), and are shown in Table 11. When available, disease-specific recommendations for physical activity are discussed in section 5 of the report. These recommendations largely promote moderate-intensity physical activity which is defined as an increase in breathing rate, an increase in HR to the level where the pulse can be felt and a feeling of increased warmth, possibly accompanied by sweating on hot or humid days. The Chief Medical Officer report also emphasised that the recommended levels of physical activity can be achieved in a number of ways including accumulating activity in shorter bouts. Shorter bouts of activity offer an easier starting point to those who are sedentary, and it can be an easier way of incorporating exercise into everyday activities rather than undertaking more structured exercise that involves joining sports clubs or classes. These recommendations are based on an emerging consensus that, overall, it is the total amount of physical activity that is most critical for health benefits.

In order for physical activity recommendations to be effective for public health improvement, it is important to promote levels of activity that are worthwhile but at the same time realistic and achievable. A large proportion of the UK now lead sedentary lifestyles and these people are the major target for physical activity interventions. In terms of public health, it is more important to encourage those who are currently sedentary to engage in moderate-intensity physical activity five times a week, than to encourage those who are already moderately physically active to increase their activity levels further.

However, it should be stressed that these UK physical activity recommendations are a minimum. As discussed in section 5 of this report, there is a dose-dependent relationship between physical activity and prevention of chronic disease. Therefore, further health benefits can be achieved by increasing physical activity levels, in terms of intensity, duration and overall volume of physical activity, beyond these minimum levels.

The benefits of greater amounts of physical activity have also been emphasised in the recently updated recommendations from the American College of Sports Medicine and the American Heart Association (ACSM/AHA) (Haskell *et al.* 2007). To promote and maintain

Table 11 Current UK recommendations for physical activity (Department of Health 2004)

Children and young people should achieve a total of at least 60 minutes of at least moderate-intensity physical activity each day. At least twice a week this should include activities to improve bone health, muscle strength and flexibility.

For general health benefit, adults should achieve a total of at least 30 minutes of at least moderate-intensity physical activity a day, on five or more days a week.

The recommended levels of activity can be achieved either by doing all the daily activity in one session, or through several shorter bouts of activity of 10 minutes or more. The activity can be lifestyle activity or structured exercise or sport, or a combination of these.

All movement contributes to energy expenditure and is important for weight management. It is likely that for many people 45–60 minutes of moderate-intensity physical activity a day is necessary to prevent obesity. For bone health, activities that produce high physical stresses on the bones are necessary.

The recommendations for adults are also appropriate for older people. Older people should take particular care to keep moving and retain their mobility through daily activity. Additionally, specific activities that promote improved strength, co-ordination and balance are particularly beneficial for older people.

health, adults aged 18–65 years need moderate-intensity aerobic physical activity for a minimum of 30 minutes on 5 days of the week, or vigorous-intensity activity for a minimum of 20 minutes on 3 days of the week. Combinations of moderate- and vigorous-intensity activity can be performed to meet this recommendation. The ACSM/AHA highlight that these activities are in addition to the light-intensity activities frequently performed during daily life (*e.g.* washing dishes) or activities of very short duration (*e.g.* walking to the car park). In addition, at least twice each week adults will benefit from activities that use the major muscles of the body that maintain or increase muscular strength and endurance. The ACSM/AHA also states that, to reduce the risk of chronic diseases and disabilities, or prevent unhealthy weight gain, it is likely that this minimum amount of physical activity will need to be exceeded.

The UK and US recommendations for physical activity are compatible with those from WHO. The *Global Strategy on Diet, Physical Activity and Health* (WHO 2004) states that individuals should engage in different levels of physical activity throughout their life; different types and amounts are required for different outcomes. Taking part in at least 30 minutes of moderate-intensity physical activity on most days of the week reduces the risk of CVD, diabetes, breast cancer and colon cancer.

6.3 Psychological barriers to physical activity

Achieving an increase in physical activity in the population is a great challenge. There are a number of psychological barriers to increasing physical activity levels and an understanding of how these operate is crucial to developing effective ways to promote physical activity. The challenge is often to translate short-term gains into the adoption and maintenance of physically active behaviours across the lifespan. Delahunty *et al.* (2006) looked at psychological predictors of physical activity in the Diabetes Prevention Program. Male gender, lower BMI, higher exercise self-efficacy, lower perceived stress, and depression and anxiety scores were found to correlate with higher baseline levels of physical activity. In particular, it is recognised that obese individuals have specific barriers to physical activity and so this has implications for the successful promotion of physical activity. Hills and Byrne (2006) have identified the following barriers to physical activity in the obese:

• perceived lack of time for activity;
• failure of health professionals to provide appropriate care and attention;
• poor experiences of physical activity;

• lack of self-efficacy;
• low self-esteem;
• low self-confidence;
• embarrassment;
• incorrect assumptions about how much physical activity to complete;
• lack of immediate rewards such as failure to lose expected weight;
• soreness, discomfort or pain as a result of exercise;
• low tolerance of exercise due to low fitness levels;
• excess weight leading to immobility;
• lack of motivation and boredom with physical activity.

Some further insights into motivation and barriers to physical activity are provided by Foster *et al.* (2005) in the report *Understanding Participation in Sport*. Concerns about body shape, fun and enjoyment and social interaction were all reasons why young girls take up physical activity or sport. Variation in the types of physical activity offered to children, particularly in physical education lessons, is important to increase physical activity levels. Barriers identified for adults included having to show an unfit body, appearing incompetent, appearing masculine for women, poor state of facilities and the cost of joining sports clubs. Older people were motivated to increase their activity levels by knowledge of health benefits and a concern about ageing.

In recognition of the psychological determinants of health behaviour, including physical activity, a number of behaviour change models have been developed. There are three well-recognised psychosocial models (theory of planned behaviour, social cognitive theory, theory of reasoned action) that have many features in common. These models refer to personal factors that affect health behaviour and, in terms of physical activity, hypothesise that behaviour change is more likely when (Foster *et al.* 2005):

• The perceived benefits of physical activity outweigh the perceived costs.
• Becoming physically active will lead to social approval, not disapproval.
• Being more active will lead to self-satisfaction and is consistent with highly valued, broader life goals.
• Desirable outcomes are within one's personal control and are achievable through one's own actions.
• There are few barriers to achieving desirable outcomes.
• Opportunities and access to physical activity are high.

A 'stages of change' model has also influenced the design of interventions to increase physical activity

levels (Foster *et al.* 2005). In short, this model proposes that behavioural change involves movement through a series of stages before change is achieved: precontemplation, contemplation, preparation, action and finally maintenance. It has been argued that different processes or strategies are required to change behaviour at these different stages, and that matching the right process to each stage is the best way to facilitate change. However, the research evidence supporting a stage-based approach to physical activity promotion is equivocal (Foster *et al.* 2005). For example, Jenum *et al.* (2006) has reported some success from a stage-based community intervention in a multiethnic district of Norway. The intervention district had a 50% relative reduction in body mass compared with the control district, and beneficial effects on lipid profile and blood pressure were also reported. But in a Dutch study by Proper *et al.* (2006), stage-based physical activity counselling carried out in a GP setting demonstrated a beneficial effect on the determinants of physical activity, but did not show any additional effect on physical activity behaviour, compared with standard advice on physical activity.

6.4 Environmental determinants of physical activity

Physical inactivity is a major public health problem and is linked to a huge burden of chronic disease. It is crucial to tackle this issue at the policy level and therefore consider the environmental factors contributing to low levels of physical activity. These have been summarised by Hills and Byrne (2006):

• declining need for physical activity in the home, workplace and community;
• lack of physical education in schools, reduced time for play, active transport uncommon;
• neighbourhood design that is not conducive to physical activity;
• transport system dominated by cars;
• use of lifts and escalators and inaccessible stairs;
• TV, computer games, internet and other sedentary entertainment;
• household appliances and labour-saving devices.

In an interesting study by Gordon-Larsen *et al.* (2006), the environmental influences on physical inactivity were all too apparent. This US study aimed to assess the geographic and social distribution of physical activity facilities and how disparity in access to them might underlie population-level physical activity and overweight patterns. An increase in the number of physical activity facilities was associated with decreased overweight and increased relative odds of achieving ≥5 bouts per week of moderate to vigorous-intensity physical activity. Similarly, NICE (2006c) have described two interventions (conducted in a military setting) that have shown that changing the environment might influence physical activity levels. These findings emphasise the connection between the built environment and physical activity.

Local authorities and town planners have an important role to play in helping people to gain the benefits of being more active, both in terms of providing appropriate sport and leisure facilities, but also by ensuring that pavements and recreational areas are of a suitable standard and that walking areas are well lit and maintained (Buttriss 2008). Although there appears to be limited scope for increasing energy expenditure at work or via domestic activities, active transport initiatives offer some scope. The journey to school is a potentially important opportunity for establishing daily physical activity in childhood, and many schemes have been introduced at governmental, national and local levels to promote active transport to school. This is supported by evidence that children who walk or cycle to school are more physically active (Cooper *et al.* 2003; 2005) and have better CRF (Cooper *et al.* 2006). The benefits of active transport are not limited to children. There is an enormous potential to increase walking and cycling over short trips, but perceived danger and inconvenience are barriers to achieving this. Unfortunately, the UK is lagging behind other countries on initiatives in this area (Pucher & Dijkstra 2003). In England and Wales the percentage of trips in urban areas made by walking is 12% and by cycling is 4%. This compares with 18% and 28% respectively in the Netherlands, for example. In terms of active transport, there are lessons to learn from other European countries that have implemented a range of policies to improve the safety of walking and cycling (Pucher & Dijkstra 2003).

6.5 Effectiveness of interventions to promote physical activity

It is of course critical to use an evidence-based approach to designing community-based interventions which aim to increase physical activity levels. Based on a systematic review by Hillsdon *et al.* (2005), the National Institute for Clinical Excellence (NICE) has issued guidance on the promotion of physical activity among adults (NICE 2006a). Hillsdon *et al.* (2005) reviewed the findings of 17 randomised controlled trials with a minimum of six months follow-up. The interventions all aimed to promote physical activity in adults but there were

marked differences in the nature of the interventions in terms of their level of supervision and delivery (home/telephoned based etc.). The review found that professional advice and guidance with continued support can encourage people, aged 16 years and older, to be more physically active. However, as the majority of studies included in the review lasted no more than a year, more research is needed to establish which methods of exercise promotion work best in the long-term. The final guidance (NICE 2006a) also took into account practitioner expertise and experience and can be summarised as follows:

Actions for primary care

Interventions can be effective in both the short- and medium-term. The important contribution of GPs needs to be combined with other expertise in exercise and behaviour change; some training needs were identified. An integrative approach to physical activity promotion is needed with pooled budgets.

Actions for community interventions

Interventions targeting individuals in community settings are effective in increasing physical activity, and are likely to be effective in producing mid- to long-term changes in physical activity. Intervention design should be based on behaviour change theories and should offer a range of moderate-intensity physical activities, especially walking. Projects should contain:

• tailored and targeted programmes to reach inactive individuals;
• regular support and contact with project staff;
• promotion of home-based walking and other moderate-intensity physical activities;
• a choice of local opportunities to be active;
• access to local specialists;
• physical activity advice and supervision for project staff and participants.

Actions for older people

Physical activity programmes for older people can be popular, well attended and effective in increasing physical activity, but they need to be designed to meet the needs of the participants. Interventions need to be targeted depending on capacity to exercise, level of independence and stated preferences for physical activity type. Programmes should be designed to incorporate existing networks and facilities that older people use, and should be organised by a partnership of health and voluntary sector agencies.

Adding further insight into the effectiveness of physical activity interventions in older people, Ashworth *et al.* (2005) compared home *vs.* centre-based physical activity programmes in older adults, using evidence from six studies. A 'home-based' programme was defined as physical activity which takes place in an informal, flexible setting, typically an individual's home. 'Centre-based' programmes were thought to be more formal, and were run for a defined period of time at a healthcare facility. Overall, home-based programmes had better adherence rates than centre-based programmes, but both types of exercise produced improvements in parameters such as perceived quality of life, HDL-cholesterol and blood pressure, when compared with controls. No statistically significant difference was seen between the two types of intervention.

In another NICE report (2006b), the effectiveness of four commonly used methods to increase physical activity was assessed: brief interventions in primary care, exercise referral schemes, pedometers, and community-based exercise programmes for walking and cycling. Brief interventions involve opportunistic advice, discussion, negotiation or encouragement and can be delivered by a range of primary and community care professionals. NICE concluded that there is sufficient evidence to recommend the use of brief interventions in primary care. Exercise referral schemes direct someone to a service offering an assessment of need, development of a tailored physical activity programme, monitoring of progress and a follow-up, but there was insufficient evidence to recommend their use. Similarly, there was insufficient evidence to support the use of pedometers, or walking and cycling schemes (organised walks/cycle rides).

In terms of workplace interventions, there appears to be some confusion regarding their effectiveness. Marshall (2004) concluded that there was little evidence of long-term effectiveness of workplace physical activity programmes. Yet Proper *et al.* (2003) concluded that there was strong evidence for a positive effect on physical activity levels and inconclusive evidence for a positive effect on CRF. NICE (2006a) concluded that although the workplace is seen to offer great potential for physical activity promotion, there are inconsistent findings on the effectiveness of interventions in the workplace. The main barriers identified were a lack of time and investment by employers.

Despite gaps in the evidence on what is known about the effectiveness of interventions to increase physical activity, the information summarised here can be a useful starting point for those designing programmes to promote physical activity. But the challenge of translat-

ing interventions (that are used to test the effectiveness of physical activity promotion programmes) into the community setting remains. Although this is rarely achieved, there is some evidence that this can be done well (Wilcox *et al.* 2006).

6.6 Risks associated with physical activity

Although the health benefits of physical activity are widely documented, it is important to consider any risks linked with performing physical activity at various levels. Overall risk is low, but there are some risks in those exercising at higher intensity and volumes and those taking part in contact sports (Department of Health 2004). Importantly, people who are embarking on a new physical activity programme or taking part in a new sport should increase their involvement gradually. When untrained or previously sedentary individuals undertake vigorous exertion suddenly, the risk of dehydration, injuries or even cardiac arrest is amplified (Melzer *et al.* 2004).

There are some general cautions that should be considered when undertaking physical activity. Prolonged exercise in the heat can lead to dehydration and electrolyte imbalance, so it important to drink enough water prior to and during exercise. Some particular groups, such as diabetics and asthmatics also need to take special care because of an increased risk of hypoglycaemia or asthmatic attack. Also, those who have pre-existing musculoskeletal disease, *e.g.* pre-existing back pain, have a higher risk of injury.

At moderate levels of physical activity there are few injuries. However, there is some risk of injury with high-intensity exercise training and participation in particular sports. Injuries with contact sports, such as football, are the most common, and activities such as rugby, diving, trampolining, gymnastics and horse riding carry some risk of spinal injuries. Overuse injuries can occur in runners, but other factors usually compound the issue such as the use of poor sports shoes, lack of training experience and a rapid increase in training intensity (Hardman & Stensel 2003). Nevertheless, most injuries are avoidable and there are many types of activity that carry a particularly low risk, such as walking.

As discussed in various sections of this briefing paper, physical activity provides the most benefit for those who are at high risk of chronic disease. This has important implications for those at risk of CVD, because physical exertion can sometimes be a trigger for cardiac events. In approximately 5% of patients with heart attack, vigorous exertion immediately preceded the onset of symptoms (Hardman & Stensel 2003). However, this transient increase in risk is much smaller among people who are accustomed to vigorous exertion than in those who are sedentary. Again, this emphasises the need for sedentary individuals to build up physical activity levels gradually.

In women who perform high volumes of exercise training (such as competitive athletes), training intensity is clearly a causal factor in menstrual disturbances (Hardman & Stensel 2003). Particular risk factors are low level of body fatness (so risk is greater in sports that require leanness such as gymnastics) and a sudden increase in training intensity or volume. Amenorrhoea (ceasing of menstrual periods) can be reversed with an increase in body fatness and a decrease in the amount of training, but if unresolved can affect fertility and also bone strength.

High levels of physical activity can also affect the immune system. Prolonged heavy physical exertion lasting longer than 90 minutes tends to lead to immunosuppression, particularly if the activity is accompanied by environmental or competitive stress (Shephard & Shek 1994).

Mood can also be adversely affected when exercise is performed in an excessive or intense manner. Although moderate exercise leads to improvements in mood, intense exercise leads to its deterioration, and such mood variations are more related to features of depression than anxiety. Peluso & Guerra de Andrade (2005) described some of the potential risks:

- *Excessive exercise:* an obsessive preoccupation with exercise and excessive training that interferes with personal and occupational relationships.
- *Body dysmorphic disorder:* alterations in body image found among some weight lifters and bodybuilders where they believe they are weak and skinny, despite their large and muscular physiques.
- *Overtraining syndrome:* usually only experienced by athletes doing excessive training, who have problems with sleep disturbance, loss of weight and appetite, reduced libido, irritability, heavy and painful musculature, emotional lability and even depression.

So overall, the majority of risks are only encountered at very high volumes of exercise or if activity has not been built up gradually, and so these risks can be minimised with a sensible approach to exercise. It is reasonable to conclude that risk exposure through physical activity is definitely outweighed by its overall benefits. Hence health authorities strongly encourage participation in moderate-intensity physical activity on most, if not all, days of the week (Department of Health 2004; Melzer *et al.* 2004).

Key points

• Physical activity is important in childhood as a means of maintaining energy balance and helping bone strength, and thus reducing the risk of chronic diseases later in life. It is also important for social interaction, wellbeing and the setting of good lifestyle habits.

• Physical activity is important throughout adulthood in order to reduce the risk of chronic diseases. Recommended physical activity levels should be maintained into old age for as long as capabilities allow, in order to counteract the age-related losses in muscle and bone, deterioration of the cardiovascular system and decrease the risk of osteoporotic fractures.

• The current recommendations for physical activity are:

  • Children and young people should achieve a total of at least 60 minutes of at least moderate-intensity physical activity each day. At least twice a week this should include activities to improve bone health, muscle strength and flexibility.
  • For general health benefit, adults should achieve a total of at least 30 minutes of at least moderate-intensity physical activity a day, on five or more days a week.
  • All movement contributes to energy expenditure and is important for weight management. It is likely that for many people, 45–60 minutes of moderate-intensity physical activity a day is necessary to prevent obesity. For bone health, activities that produce high physical stresses on the bones are necessary.

• A number of psychological barriers to physical activity have been identified, especially for those who are obese and need to lose weight. These include issues related to body image, poor confidence and lack of immediate rewards from physical activity.

• A number of behaviour change models have been used to identify personal factors that can help change physical activity behaviour. It is also proposed that change in physical activity behaviour is more likely to be effective when promotion strategies take into account the stage at which an individual is considering or achieving a change in lifestyle.

• There are a number of environmental factors which contribute to low levels of physical activity and these should be tackled if significant changes to population level physical activity are to be achieved. Policies which support active transport initiatives have proved to be effective in other countries and thus have greater potential in the UK.

• NICE offers a range of guidance on the effectiveness of different methods of promoting physical activity. However, current research is limited and ongoing work may provide additional guidance in the coming years.

• There are a small number of risks associated with physical activity, many of which are only linked to contact sports or physical activity at very high intensities. Many of the risks of physical activity can be avoided by building up physical activity levels gradually.

7 Conclusions

This paper describes how physical activity substantially reduces the risk of chronic disease, and its importance for overall health and wellbeing. Yet, physical activity levels in the UK are low. Only 35% of men and 24% of women reach the recommended 30 minutes of moderate-intensity physical activity at least five times a week, and levels are even lower in low-income groups. Physical inactivity is a major public health problem in the UK. At best, there has been a modest increase in overall physical activity levels from 1997 onwards, but physical activity remains an infrequent event for over half the population. Tackling this issue will bring many benefits to the population, particularly saving lives and reducing healthcare costs. And because physical activity also provides opportunities for social interaction and engagement with the community, increasing activity levels can also lead to a better quality of life.

In recent years, various schemes have been developed that aim to improve physical activity levels in the UK. For example, government-funded campaigns have been launched by the Sports Council/Sport England to increase mass participation of adults and children in sport. More than £750 million of mainly lottery funds has been allocated to increasing sport facilities and sports co-ordinators in schools (Department for Culture, Media & Sport 2001). In the Department for Transport's *Walking and Cycling Action Plan*, employers are encouraged to develop workplace travel plans that promote walking and cycling to work (Department for Transport 2004). Charities have also been active. The British Heart Foundation is running a '30 a day' campaign and Sustrans runs a number of projects to promote cycling and walking. However, the effectiveness of such schemes is uncertain, and the evidence on which to base the design of new health promotion initiatives is limited.

We know that a range of environmental factors contribute to physical activity levels, for example the increasing use of cars for travelling to work (Fox & Hillsdon 2007), the increasing use of household appli-

ances and labour-saving devices, and neighbourhood design that is not conducive to physical activity. As a result, there is a strong argument that changes to national policies need to be at the heart of strategies to tackle physical inactivity.

Fox and Hillsdon (2007) have argued that physical activity promotion should be a critical element of urban planning and design. Town planners should design neighbourhoods that include spaces to be physically active, such as parks. Transport policies are also important because fear of traffic and the general unpleasant impact traffic has on the ability to walk or cycle comfortably, are both barriers to increasing physical activity. Although there appears to be limited scope for increasing energy expenditure at work or via domestic activities, initiatives to promote active transport offer great potential. Lessons can be learned from the success of active transport initiatives in other European countries. Access to recreational facilities and the affordability of classes (*e.g.* dance classes) are also important, particularly as currently there are fewer opportunities for people in the most deprived neighbourhoods (Fox & Hillsdon 2007). Further investment in sport and sports facilities is also needed.

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