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PHYSIOLOGICAL RESPONSES AND MOOD STATES AFTER DAILY REPEATED PROLONGED EXERCISE*

Ilkka Väänänen

LIKES-Research Center for Sport and Health Sciences, Jyväskylä, Finland

Department of Physiology, Faculty of Medicine, University of Kuopio, Kuopio

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Ilkka Väänänen

ABBREVIATIONS

ACTH	Adrenocorticotropic hormone
a.m.	Morning, (ante meridiem)
ANOVA	Analysis of variance
CC	Circumference of the calves
CT	Circumference of the thighs
CK	Creatine kinase
CNS	Central nervous system
CO_2	Carbon dioxide
DOMS	Delayed onset muscle soreness
FSH	Follicle stimulating hormone
HR	Heart rate
IFMA	Immunofluorometric assay
IU	International unit of concentration
HF	Hip flexors
KE	Knee extensors
KF	Knee flexors
LH	Luteinizing hormone
LTPA	Leisure-time physical activity
MET	Metabolic equivalent
O_2	Oxygen
OPA	Occupational physical activity
PA	Physical activity
p.m.	Afternoon, (post meridiem)
PST	Physical stress theory
POMS	Profile of mood states
RIA	Radioimmunometric assay
RPE	Rating of perceived exertion
ROM	Range of movement
VAS	Visual analogue scale
VO_2	Oxygen uptake
VO_2R	Oxygen uptake reserve

This review is based on the following original publications, which will be referred to in the text as Studies 1-6:

1. Väänänen, I., Mäntysaari, M., Huttunen, P., Komulainen, J. and Vihko, V. (1997) The effects of a 4-day march on the lower extremities and hormonal balance. *Military Medicine* **162,** 118-122.

2. Väänänen, I., Vasankari, T., Mäntysaari, M. and Vihko, V. The effects of a 4-day march on the gonadotrophins and mood states of military men. *Military Medicine* **169** (in press).

3. Väänänen, I., Mäntysaari, M. and Vihko, V. (2001) Soldiers' physiological and psychological loading during a 4-day march. *Annales Medicinae MIlitaris Fenniae* **76,** 59-67.

4. Väänänen, I., Vasankari, T., Mäntysaari, M. and Vihko, V (2002) Hormonal responses to daily strenuous walking during 4 successive days. *European Journal of Applied Physiology* **88,** 122-127.

5. Väänänen, I. and Vihko, V. Physiological and psychological responses to 100 km cross-country skiing during 2 days. *Journal of Sports Medicine and Physical Fitness* (in press).

6. Väänänen, I., Vasankari, T., Mäntysaari, M. and Vihko, V. Hormonal responses to 100 km cross-country skiing during 2 days. *Journal of Sports Medicine and Physical Fitness* (in press).

CONTENTS

Väänänen, I. (2004) Physiological responses and mood states after daily repeated prolonged exercise. *Journal of Sports Science and Medicine* **3, Suppl. 6,** 1-43.

ABSTRACT

The purpose of this study was to describe the physiological responses to daily repeated acute but non-competitive prolonged exercise during a 4-day march and a 2-day cross-country ski event to the cardiorespiratory, autonomic nervous, musculoskeletal and endocrine systems. Mood states were also evaluated after these repeated exercises.

The data of these short-term follow-up (reversal) field trials was collected from healthy, 23 to 48 year old Finnish male soldiers in 1993 (n=6) and 1994 (n=15) during the "International Four-Day Long-Distance March" in Nijmegen, The Netherlands, and from ten healthy, 22 to 48 year old Finnish male participants in 1995 during a 2-day Finlandia Ski Race in Lahti, Finland.

Acute cardiovascular responses were estimated by measuring the heart rate during exercise. The responses of the autonomic nervous system were estimated by measuring the heart rates during the orthostatic test. The musculoskeletal responses were estimated by measuring the perceived pains, flexibility, functional strength, use of elastic energy and oedemic changes of the lower extremities. Hormonal responses were estimated from the urinary excretion of catecholamines, and the concentrations of serum cortisol, testosterone, luteinizing (LH) and follicle stimulating hormone (FSH). Mood states were assessed with the Profile of Mood States (POMS) questionnaire.

Daily walking time was 7-10 hours while the skiing time was 3 hours. Average heart rate during walking was 59% and skiing 87% of maximum heart rate. Morning heart rate in the supine position increased progressively through the marching period but not through the skiing experiment. After the first day, perceived pain increased significantly and remained at a similarly increased level until the end of the exercise period. Leg measurements showed no signs of oedema, decreases in flexibility, or functional strength. Catecholamine excretion rates during marches indicated cumulatively increased sympathoadrenal stress. The acute increasing effect of a single walking session on cortisol was seen only after the first day when there was a 60% increase. Responses after skiing were greater (2.2- and 2.6-fold). The acute reductions in testosterone concentrations were seen after the first two marching sessions, when they were decreased by 18-22%. LH concentration was decreased by 31-44% after the second and third day. For FSH concentrations suppression was consistently seen after the second march, but not after skiing. The total mood disturbance score remained unchanged during the events. The Fatigue-Inertia affective state was higher after exercise than before the events.

This study demonstrates that the pituitary-gonadal axis, excluding the secretion of FSH and the adrenal cortex, adapted to four days of repeated moderate 8 h walking, but not to two days of repeated strenuous 3 h skiing. However, when using the sensitive IFMA, which can detect low concentrations of gonadotropins, secretion of FSH was seen to remain reduced and no adaptation was seen in walking. This study indicated that daily repeated long lasting acute but non-competitive walk and skiing of intensity at approximately 60-90% of the maximum heart rate is well within the physiological capabilities of individuals with good aerobic capacity.

KEY WORDS: Hormones, functional capacity, lower extremities, muscle soreness, mood state, adaptation, recovery, walking, skiing.

1. INTRODUCTION

The human organism is in a homeodynamic state. When extrinsic or intrinsic forces threaten homeostasis, the state is called stress. Stress is defined as a physical, chemical, or psychological factor or combination of factors, which pose a threat to the homeostasis, or well-being of an organism. Stress produces a defensive response of which infection, physical or emotional traumas are examples (International dictionary of medicine and biology in three volumes, 1986, p. 2719). A nongenetic change in an organism, which takes place in response to an environmental stimulus and a progressive reduction in the sensitivity of a sense organ following prolonged exposure to the same sensory stimulus, is defined as adaptation (International dictionary of medicine and biology in three volumes, 1986, p. 39). According to Physical Stress Theory (PST) (Mueller and Maluf, 2002) tissue adaptation takes place in response to physical stress. The level of exposure to physical stress is a composite value, defined by the magnitude, time and direction of stress application. Physical activity normally improves health by increasing the stress threshold on a broad range of tissues, making them more tolerant of subsequent physical activity and thereby less likely to be injured. However, if tissues are unable to adapt to meet the demands of a given posture or task, injury occurs. For example, injury can occur, if a high-magnitude stress is applied for a brief duration or a low-magnitude stress is applied for a long duration, and if a moderate-magnitude stress is applied to the tissue many times. In exercise loading, attention focuses on factors such as the frequency and length of workouts, the type of exercise as well as the speed, intensity, duration and repetition of the activity. In the recovery phase, homeostasis must be re-established to allow the body to respond to stress so that adaptation can occur. The regenerative process still continues after the restoration of the previous homeostatic state with a resulting overcompensation or supercompensation (Harre, 1975; Viru, 1984). Ideally, subsequent exercise/training session should not take place until supercompensation has occurred (Harre, 1975). Among physiological responses to exercise there are also psychological responses, which are usually explained by endorphin, monoamine, thermogenic or distraction hypothesis, or opponent-process model (Leith, 1994).

The acute effects of a single bout of several types of physical exertion and the effects of long-term physical training are quite well documented. Far less is known about the responses to daily repeated strenuous physical exertion and the loading versus recovery/adaptation. Physiological responses in professional athletes, of daily repeated running and cycling are quite well known, however very few investigator, have attempted to assess both physiological and psychological parameters during periods of overloading micro-cycle exercising, despite the demonstrated efficacy of such an approach within recommendations and within exercise and sport science research (e.g., O'Connor et al., 1989; Fry et al., 1991; Hooper and McKinnon, 1995). There are countless numbers of sustained extreme exercises to participate in for cyclists, orienteers, paddlers, rowers, skaters, skiers, swimmers, walkers and other extreme seekers in the world. Many of these events are favoured not only by regularly training and competitive athletes but also by the population at large.

In exercise physiology applied research tends to address immediate problems, to real-world settings. Quasi-experimental design fits to settings that are more real world while still controlling as many of the threats to internal validity as possible. It has less control over the research settings than traditional experimental designs, but it gives results that are of direct value to practitioners (Thomas and Nelson, 1990, p. 5). Because it is a natural research setting in which the experimental design is introduced into the data collection procedure, a short-term follow-up (reversal) field trial was used in this thesis. The general purpose was to describe the daily physiological responses and to understand the contextual action during the prolonged daily physical stress more holistically. Further, psychological loading and responses to mood states after repeated various (intensity, duration, mode/ type) prolonged exercises of healthy men were estimated.

2. REVIEW OF THE LITERATURE

2.1. Terminology

The term *load* is defined as external forces, which act upon a body (Nigg et al., 1984) whereas *overload* is a load greater than the rated load, which can cause damage. *Overloading* is the condition resulting from excessive sensory stimulation, in which the stimuli are too intense or too rapid for an individual to respond appropriately. (International dictionary of medicine and biology in three volumes, 1986, p. 2048).

Homeostasis is the relative stability or constant condition (homeodynamics) of the internal environment of an organism, which is preserved through feedback mechanisms despite the presence of influences capable of causing profound changes and those processes considered collectively by normal organisms which homeostasis is maintained (International dictionary of medicine and biology in three volumes, p. 1986, 1331; Guyton and Hall, 2000, p. 3).

Steady state is any condition which remains constant at a given point in time because of the presence of opposite forces on processes which cancel out one another's effects (International dictionary of medicine and biology in three volumes, 1986, p. 2692).

Supercompensation is a state of improved work capacity, above the level of which the person has recently been capable. This has been characterised as a state of balanced homeostasis with homeostatic markers reflecting either baseline values or improvements, depending upon the nature of the variable (Fry et al., 1991).

Adaptation is the advantageous change or changes of behaviour, physiology, or structure by which an organism modifies itself to fit into a particular environment. A nongenetic change in an organism which takes place in response to an environmental stimulus and a progressive reduction in the sensitivity of a sense organ following prolonged exposure to the same sensory stimulus are also defined as adaptation (International dictionary of medicine and biology in three volumes, 1986, p. 39).

Physical activity (PA) is defined as any body movement produced by contraction of skeletal muscle, which substantially increases energy expenditure. The *dose* is described by intensity, frequency, duration, mode/type, and purpose of the PA (Bouchard and Shephard, 1994; U.S. Department of Health and Human Services, 1996; Howley, 2001). *Frequency* is described as the number of activity sessions per day, week, or month. Duration typically refers to the length of activity in each session. *Intensity* describes, in relative or absolute terms, the effort associated with the PA (Howley, 2001). Physical activity is frequently categorised by the context in which it occurs (U.S. Department of Health and Human Services, 1996).

Leisure-time physical activity (LTPA) is a broad descriptor of the activities one participates in during their free time (e.g., dance, gardening, hiking, walking, etc.) based on personal interests and needs. The common element between these activities is the resulting increased energy expenditure, although the intensity and duration can vary considerably (Bouchard and Shephard, 1994, 77). The absolute intensity of LTPA describes the actual rate of energy expenditure. Common expressions include: oxygen uptake ($l \cdot min^{-1}$), oxygen uptake relative to body mass ($ml \cdot kg^{-1} \cdot min^{-1}$), kcal or kJ per minute, and multiples of resting metabolic rate (METs) (Howley, 2001).

Occupational physical activity (OPA) is associated with the performance of a job, usually within the time frame of an 8-h work day (Howley, 2001).

Training is the result of biological adaptations achieved after repeated exercise bouts over a period of several days, weeks, or months of exercise (Edington and Edgerton, 1976, p. 8).

Exercise (exercise training) is usually performed on a repeated basis over an extended period of time. It is planned, and structured to improve or maintain one or more components of physical fitness (Bouchard and Shephard, 1994; U.S. Department of Health And Human Services, 1996). Different exercises have different biological requirements. These requirements could be classified according to the speed of movement, resistance to the movement, and duration or time over which the movement is repeated (Edington and Edgerton, 1976, p. 4-7). To understand the suitability of a given exercise, we must understand the specific effects of that exercise-form from the molecular level to the effects on the total body (Edington and Edgerton, 1976, p. 4).

Overloading training is the process of stressing an individual to provide a stimulus for adaptation and supercompensation (Fry et al., 1991). *Training fatigue/stress* is the normal fatigue that is experienced following several days of this kind of heavy training associated with an overloading stimulus. This fatigue is reversed and supercompensation occurs by the end of the last few days of a period of reduced training load (regeneration microcycle) (Kuipers and Keizer, 1988; Fry et al., 1991). *Exhaustion* is the result of the body's inability to meet the exercise demands (Edington and Edgerton, 1976, p. 3).

Overtraining and *physical overstrain* are the non-differentiated general terms for any short- or long-term condition which indicates that the individual has been stressed by training and extraneous stressors to the extent that a person cannot perform at an optimum level following an appropriate regeneration period (Kuipers and Keizer, 1988; Fry et al., 1991; U.S. Department of Health and Human Services, 1996).

Overreaching is the state in which an accumulation of training stress results in a short-term deterioration of performance capacity with or without related physiological and psychological signs and symptoms of overtraining, and in which the restoration of performance capacity may take anywhere from several days to several weeks (Kuipers and Keizer, 1988; Budgett, 1990; Fry et al., 1991; Fry and Kraemer, 1997).

Overtraining syndrome and *staleness* are the states of the long lasting imbalance between training and recovery. Muscular overstrain occurs when the muscular stress tolerance is exceeded by exercise, resulting in transient local fatigue and muscle soreness thus it may be considered as local overtraining (Kuipers and Keizer, 1988).

Training stressors result from the physical, physiological, and psychological training workloads administered during overload training. *Extraneous stressors* are those resulting from activities and psychological forces related to lifestyle (Fry et al., 1991).

2.2. Loading and adaptation mechanisms during physical activity

Load depends on the external and internal influences, as well as movement. External parameters could be equipment (e.g., backpack), shoe and surface. Internal factors are the anthropometrical facts and the individual situation (from both a physiological and psychological point of view). Movement may influence the load of the human body concerning the type as well as the frequency of a certain type of movement (Nigg et al., 1984). A specific exercise will elicit a specific response in a specific individual at a specific point in time (Edington and Edgerton, 1976, p. 7). The attention in exercise loading focuses on factors such as frequency and length of workouts, type of exercise, speed, intensity, duration, and repetition of the activity. It also requires that the progress of the load is observed, as well as the recovery intervals (Fowler, 1983).

If the volume of the physical activity is too large or the recovery is too short, training can lead to problems. There are many risk factors for training injuries, which could be categorised either as intrinsic or extrinsic in nature (Jones and Knapik, 1999). Intrinsic factors are the inherent characteristics of individuals, anatomical characteristics, physical fitness, lifestyle and behavioural characteristics. Extrinsic factors are external to the individual, such as a physical training programme (e.g., high running mileage, frequent marching and running), equipment, terrain and weather conditions, which all influence the risk of injury.

The human body is able, to some degree, actively adapt to physical stress. Adaptation to life conditions, change in the external environment and any kind of bodily activity are always directed toward maintaining or restoring the constancy of the body's internal milieu (Viru, 1984; Viru and Smirnova, 1995). In situations which require the activation of adaptation processes, the main events within an individual are described by Viru and Smirnova (1995) in the following manner: "The agent (stressor) acts, by various pathways, on the structures of the central nervous system. If the required intensity of the homeostatic reactions is high, or it is necessary to maintain them for a prolonged duration, the mechanisms of general adaptation (mobilisation of energy reserves and protein resources, and activation of defence faculties) will be activated." During the recovery period after acute adaptation, and to a lesser extent during acute adaptation, the dynamic reserves are used extensively for the adaptative synthesis of the enzymes and structural proteins to restore the functional capacity of cellular structures that had been highly active during acute adaptation. Depending on the intensity of the inductive stimulus of adaptive protein synthesis, it may result in the production of such an amount of proteins as to warrant further development of related functional possibilities. The latter is based on the morphological and metabolic improvement. If the action inducing such adaptive synthesis of proteins is repeated with sufficient frequency, a stable adaptation develops together with elevated levels of morphological and metabolic improvement of related cellular function. (Viru, 1984)

In Edington and Edgerton's (1976, p. 10) model, daily exercise "sets up" the body so that subcellular mechanisms are stimulated to bring about those adaptive changes that characterise the "trained state". In other words something specific about the act of the exercise stimulates the cells to adapt so as to become better prepared to protect against this same exercise stress. It is highly likely that the exercise "sets up" the cell, while the actual adaptation occurs during the recovery phase. Both short- and long-term adaptations take place in response to an exercise stress. Short-term adaptations, which occur during the actual exercise, mainly involve the conversion of an inactive component to active chemicals. Long-term adaptations, which account for the primary training adaptations, are mainly concerned with the increased amounts of primary proteins (Edington and Edgerton, 1976, p. 10).

The core principle of the Physical Stress Theory (PST) is the adaptation in response to physical stress. The level of exposure to physical stress is a composite value, defined by the magnitude, time and direction of stress application (Mueller and Maluf, 2002). Movement can have beneficial (e.g., hypertrophy) as well as detrimental effects (e.g., overuse injury) on the tissues of the body. Changes in the relative level of physical stress cause a predictable adaptive response in biological tissues (epithelial, connective, muscular and nervous), which combine to form organs (i.e., cardiorespiratory, integumentary, musculoskeletal, and neuromuscular systems). The PST proposes that tissues accommodate to physical stresses by altering their structure and composition to best meet the mechanical demands of routine loading. Deviations from routine or steady state loading provide a stimulus for adaptation, which allows tissues to meet the mechanical demands of a novel environment.

According to the PST, there are five characteristic responses to physical stress: decreased stress tolerance, maintenance, increased stress tolerance, injury and death (Mueller and Maluf, 2002). Tissue homeostasis occurs when tissue degeneration equals tissue production. The range of stress levels, which promotes tissue homeostasis, is defined as the maintenance stress range. This steady state or equilibrium response occurs when tissues are exposed to a level of stress to which they have become accustomed to. When the maintenance range is exceeded, it results in an increased tolerance of tissues to subsequent stresses. Although overload can improve stress tolerance, adequate recovery between bouts of increased stress is needed for this adaptive response to occur. Excessively high levels of physical stress can result in tissue injury. When tissues are unable to adapt to meet the demands of a given posture or task, injury occurs.

2.3. Physiological responses to prolonged exercise

Response is characterised as any organic process elicited by a stimulus, as a muscular or glandular process or as a biochemical or immunochemical reaction (International dictionary of medicine and biology in three volumes, 1986, p. 2471) where reaction is defined as any response to a stimulus or other event (International dictionary of medicine and biology in three volumes, 1986, p. 2419). When challenged with any physical task, the human body responds through a series of integrated changes in function that involve most, if not all, of its physiological systems (e.g., cardiorespiratory, nervous, musculoskeletal, endocrine and immune systems) (U.S. Department of Health And Human Services, 1996).

Physical exercise is a stimulus (stress) to which the body responds through the so-called alarm reaction: energy yield is increased, requiring muscles thus functional reserves are mobilized, hormones are secreted, and defence mechanisms are activated (Selye, 1975; Viru, 1984). These responses are mediated by both neural and humoral mechanisms related to the function of the autonomic nervous system: the activation of the hypothalamus, hypophysis, sympathetic nervous system and stress hormone (e.g., catecholamines, cortisol) secretion.

2.3.1. Cardiorespiratory system

The primary functions of the cardiorespiratory system are to provide the body with oxygen (O_2), nutrients, removal of carbon dioxide (CO_2) and other metabolic waste products, maintain body temperature and acid-base balance, and the transportation of hormones from the endocrine glands to their target organs (e.g., Guyton and Hall, 2000, p. 144).

The cardiorespiratory system responds predictably to the increased demand of exercise. It is directly proportional to the skeletal muscle oxygen demands where oxygen uptake (VO_2) increases linearly with increasing rates of work (e.g., McArdle et al., 2000, p. 290-291). The intensity of exercise can be evaluated by recording the heart rate (HR) (Gilman, 1996). Calculating the average HR and comparing this to both the maximum HR (HR_{max}) and the HR at rest (HR_{Basal}), the relative HR of the workload can be calculated (Karvonen and Vuorimaa, 1988).

Oxygen uptake (VO_2, $ml \cdot min^{-1}$) during walking with centrally carried load and heavy footwear has been calculated for men as follows:

$$VO_2 = 4.1m_b + 0.367(m_b + m_{load}) \cdot v^2 + 2.017m_{shoe} \cdot v^2$$
(Holewijn et al., 1992)

where m_b is body mass (kg), m_{load} is mass of centrally carried load (kg), m_{shoe} is shoe mass (kg), v is walking velocity ($km \cdot h^{-1}$).

2.3.2. Autonomic nervous system

The autonomic system operates at a subconscious level and controls many of the internal organ's functions, including the pumping activity of the heart, movements of the gastrointestinal tract, and glandular secretion (e.g., Guyton and Hall, 2000, p. 4).

Reduced basal (morning) heart rate is a classic effect of functional adaptation to endurance exercise training (e.g., McArdle et al., 2000, p. 200, 370). On the contrary, elevated morning heart rate may be accompanied in overreaching and may reflect an early stage in the development of the overtraining state (Dressendorfer et al., 1985; Kuipers and Keizer, 1988; Dressendorfer et al., 2000). At rest, the HR depends on complex neurohumoural interactions (Dressendorfer et al., 1985): afferent nerve traffic from specialized receptors sensitive to pressure, volume, or chemical changes in the heart, blood vessels, lungs or kidneys; reflex and tonic discharge of cardiovascular centers in the brain stem that receive incoming afferent impulses and higher commands from the hypothalamus and cerebral cortex; the balance of efferent impulses in sympathetic (adrenergic) and parasympathetic (cholinergic) nerve fibers to the cardiac pacemaker; activity of beta-adrenergic and cholinergic membrane receptor sites; the influence of circulating catecholamines; and the intrinsic rate of pacemaker discharge. In addition, local temperature and pH, substrate utilization for energy metabolism could modify heart rate (Roussel and Buguet, 1982; Dressendorfer et al., 1985). The initial changes in HR after standing up are solely mediated by withdrawal of vagal tone (Ewing et al., 1980).

2.3.3. Musculoskeletal system

The musculoskeletal system consists of the peripheral parts of the motor system and comprises muscle and the connective tissue elements that form the skeleton (e.g., Enoka, 1994, p. 241). Its primary purpose is to define and move the body. To provide efficient and effective force, muscle adapts to demands. In response to demand, it changes its ability to extract oxygen, choose energy sources, and rid itself of waste products. The prolonged and strong contraction of a muscle leads to the state of muscle fatigue ("nutrient fatigue"), which is almost in direct proportion to the rate of muscle glycogen depletion (e.g., McArdle et al., 1991, p. 377; Guyton and Hall, 2000, p. 77). Therefore, most muscle fatigue results simply from an inability of the contractile and metabolic processes of the muscle fibers to continue supplying the same work output. However, the transmission of the nerve signal through the neuromuscular junction can diminish after intense prolonged muscle activity, thus further reducing muscle contraction ("neural fatigue" e.g., McArdle et al., 1991, 377; Guyton and Hall, 2000, p. 77). As muscle function becomes impaired during prolonged submaximal exercise, additional motor-unit recruitment takes place to maintain the required force output for the particular activity (e.g., McArdle et al., 1991, p. 377).

Strenuous physical activity can have diverse effects on muscle, ranging from the subcellular damage of muscle fibers to stretch-induced injuries (strains). The subcellular damage frequently produces an inflammatory response and is associated with muscle soreness that begins hours after the exercise has been completed (delayed onset muscle soreness, DOMS). In contrast, strain injuries typically occur as an acute painful injury during high-power tasks and require clinical intervention (e.g., Enoka, 1994, p. 277-278).

Delayed onset muscle soreness is characterized by tenderness, stiffness and pain in the exercised muscles, decreased flexibility, and impaired neuromuscular performance as well as muscle oedema (e.g., Armstrong, 1984; Cleak & Eston, 1992). DOMS is often observed in subjects unaccustomed to exercise (Ebbeling and Clarkson, 1989; Appell et al., 1992; Kuipers, 1994) or related to unusually prolonged or strenuous (Dressendorfer and Wade, 1983; Miles & Clarkson, 1994) exertion. Although after four days of 187% increased cycling training load the muscle soreness level was not changed (Filaire et al., 2002). The idea that an unusual increase in physical activity may be associated with muscle tissue damage prevails widely (e.g., Koplan et al., 1982; Dressendorfer et al., 1991). For example, a marathon run can cause an acute loss of muscle function (Sherman et al., 1984; Nicol et al., 1991a; 1991b; Kyröläinen et al., 2000) and increased turgidity may be found as a symptom of overreaching or short-term overtraining (Kuipers and Keizer, 1988). A sensation of discomfort in skeletal muscles is most evidenced one to two days following exercise (MacIntyre et al., 1995).

2.3.4. Endocrine system

The endocrine system integrates physiological responses and plays an important role in maintaining homeostatic conditions at rest and during exercise (e.g., Guyton and Hall, 2000, p. 5, 836). Major endocrine organs are the pituitary, thyroid, parathyroid, adrenal, pineal, and thymus glands. Several other body organs contain discrete areas of endocrine tissue, which also produce hormones. These include the pancreas, gonads, and hypothalamus (e.g., McArdle et al., 1991, p. 384). Secretion of hormones rarely occurs at a constant rate. It must be adjusted rapidly to meet the immediate demands of the changing bodily function. The concentration of a particular hormone in the blood is a function of the quantity of hormone synthesized in the host gland and the amount released into the blood. For a short period, it is possible for hormone release to exceed its synthesis. The plasma concentration of a hormone is referred to as the "secreted amount". In most cases, the rate of removal is measured in the urine and it is equal to the rate of release (e.g., McArdle et al., 1991, p. 388).

Endocrine glands are stimulated three ways: hormonally, humorally, and neurally (e.g., McArdle et al., 1991, p. 388). Responses of circulating hormones to exercise have been divided into three groups: fast, modest rate and delayed responses (Viru, 1992). The fast response is characterized by a rapid increase in the concentration of hormones in blood plasma within the first few minutes of exercise. Modest responses are characterized by a gradual increase in the hormone concentration, which may continue up till the end of the exercise or longer. On the other hand, a gradual increase during the first period of exercise may be followed by a levelling-off towards a constant level or by a declining trend in the hormone concentration (Viru, 1992). The mechanism by which the endocrine function is rapidly activated is connected with the functions of nervous centers and a high rate of transfer of the nervous influences to the endocrine glands.

In response to an episode of exercise, many hormones, such as catecholamines, are secreted at an increased rate (Richter, 1986; U.S. Department of Health And Human Services, 1996). This secretion is related to the cardiovascular and metabolic adjustments of the working tissues. The increase of epinephrine output is related to the intensity of effort and causes the constriction of essentially all of the blood. It also causes the increased activity of the heart, and the inhibition of the gastrointestinal tract (e.g., Guyton and Hall, 2000, p. 703).

The central nervous system (CNS) maintains and regulates cortisol production and secretion through the hypothalamus-pituitary-adrenal axis. Cortisol is secreted in bursts, which are superimposed on a circadian rhythm that has its peak in the early morning hours and its nadir at the initial stages of sleep (Kuhn, 1989). The response of cortisol to physical exercise is caused by a rise in adrenocorticotropic hormone (ACTH) (Schwartz and Kindermann, 1990) and is best seen 20 to 30 minutes after the stimulus (Kuhn, 1989). Another theory for the exercise induced changes in serum cortisol was proposed by Galbo (1981) who concluded that it is removed from plasma at higher rates during work loads below 50% of maximal oxygen uptake (VO_{2max}) than at rest. In a study by Duclos et al. (1997) neither brief nor prolonged light exercise induced any significant variation in plasma ACTH or cortisol concentrations. Plasma ACTH and cortisol concentrations increased only, if the exercise was intense and prolonged. The training factor did not modify the intensity or duration thresholds for the activation of the pituitary-adrenocortical response to exercise. Pestell et al. (1989) have found as a model of chronic physical stress, a significantly altered baseline hormonal state as reflected in the primary mediators of the stress response, the catecholamines and the hypothalamic-pituitary-adrenal axis. Their response to severe exercise is distinct from that of untrained individuals in whom conjugated catecholamines decrease and ACTH increase. This may represent hormonal adaptation to prolonged stress.

After four days of 187% increased cycling training load the testosterone cortisol ratio decreased, and returned to the control level within 48 h of recovery (Filaire et al., 2002). During three weeks of continuous intense cycling competition both testosterone and cortisol decreased (Fernández-Garcia et al., 2002). However, no change was detected in serum gonadotropins using the radioimmunometric assay (RIA), a far less sensitive method for detecting very low concentrations of gonadotropins than the immunofluorometric assay (IFMA) (Jaakkola et al., 1990; Huhtaniemi et al., 1992; Lucia et al., 2001).

Exercise-induced changes in testosterone concentration can be caused by a change in the production rate and altered binding or change in clearance (Tremblay et al., 1995). Several other mechanisms (haemoconcentration, decreased hepatic blood flow) could be involved, as well (Tremblay et al., 1995). During prolonged exercise, changes in serum testosterone concentration may be caused by direct testicular suppression or mediated through the hypothalamus-pituitary level (Aakvaag et al., 1978b). Tanaka et al. (1986) concluded that the cause is reduced testosterone secretion, which occurs in spite of increased stimulation of the hypothalamic-pituitary unit.

2.4. Psychological responses to prolonged exercise

Mood is an enduring but not permanent emotional predisposition to feel (International dictionary of medicine and biology in three volumes, 1986, p. 1800) and react or behave in a certain way (Sutherland 1989, p. 266).

The “feel better” phenomenon after exercise (e. g., Leith, 1994, p. 135) is often quoted, and a large body of research have demonstrated a positive link between exercise and affective states. Mood improvements following acute and chronic bouts of exercise have been reported (e. g., Raglin, 1990), but controversial results have been found, for example, when endurance athletes undergo intensified programs of heavy training. After three days of increased swimming training, mood disturbance increased (Morgan et al., 1988; O’Connor et al., 1991), but there was no significant mood response to four days 187% increased cycling training load (Filaire et al., 2002). The mood of the experienced cadets before a ranger training course was already reduced before the first day, which indicates the anxious anticipation before the start of a very strenuous course (Opstad et al., 1978).

2.5. Walking as an exercise mode

Walking is a comfortable exercise type for all adults, and it does not require special facilities or exercise equipment, except shoes. Walking campaigns (e.g., Ståhl and Laukkanen, 2000, p. 35-36) have been arranged to get people involved in physical activity. Walking is moving in such a way that the full body-mass has alternate permanent contact with the ground, via the right and left foot. It is a rhythmic, aerobic activity involving large muscle groups, confering several benefits for fitness and health with minimal adverse effects (Morris and Hardman, 1997). In 1997 68% of the Finnish population was involved in walking whereas the EU average was 31% (de Almeida et al., 1999). In 2001-2002 there were almost two million active walkers in Finland (Suuri kansallinen liikuntatutkimus 2001 - 2002, 2002, p. 20).

There are several types of walking (Ståhl and Laukkanen, 2000, p. 5). Soldier’s rhythmic walking is marching. Wandering in nature is called hiking. Load carriage by backpack is common with these. Pace walking is a walking pattern where the pace varies from slow to fast, as in interval type training. Power walking has been developed to increase the intensity of walking by adding weights to the hands, wrists, ankles, and torso. Arms are kept at a 90-degree angle. Fitness walking and health walking both refer to a walking programme designed to enhance fitness or health. Nordic walking exercise uses lightweight walking poles, similar to those used in cross-country skiing, to balance and make walking a more effective total body activity. Snowshoe walking with poles is a popular alternative for those willing to exercise in natural surroundings during the winter (Ståhl and Laukkanen, 2000, p. 5).

In research, walking has been included e.g., in weight maintenance and weight reduction programmes (e.g., Fogelholm et al., 2000), and in studies on biochemical risk factors for ischaemic heart disease (e.g., Huttunen et al., 1979; Griffin et al., 1988). In several epidemiological studies (e.g., Manson et al., 1999) brisk walking has been associated with reduction in the incidence of coronary heart disease among women. In a golf study (Parkkari et al., 2000) regular walking had many positive effects on the health and fitness of sedentary middle-aged men. Golf players were characterised to have high adherence and low risk of injury and therefore walking was considered a form of health-enhancing physical activity (Parkkari et al., 2000).

2.6. Cross-country skiing as an exercise mode

Cross-country skiing combines the actions of the arms and legs, which has been proclaimed as one of the best overall aerobic exercises. It can be performed using different techniques (e.g. classical and free) (Eisenman et al., 1989). There were 732,000 skiers in Finland in 2001-2002. Skiing ranked the third when compared to the volume of participants in other types of activities (Suuri kansallinen liikuntatutkimus 2001 - 2002, 2002, p. 20).

Classical technique involves the same rhythmic arm and leg movements observed in walking. The most common classical technique is diagonal striding. This style consists of alternating arms and legs in a rhythmic fashion. As a pole is planted, the opposite leg pushes off. In some terrain conditions higher velocity can be achieved using a single kick, double pole variation, where a double poling motion uses both arms to push off simultaneously. A skier can also double pole without a kick. The classical technique incorporates a kick, glide and poling phase, which are repeated. The ability to diagonal stride depends upon technical skill, the ability to work at a high percentage of VO_{2max}, economy of motion, and a myriad of motivational factors. Effective classic technique necessitates sufficient leg strength and balance to permit the weight to be supported on one leg during the glide, but the actual strength required is not great. (Eisenman et al., 1989; Smith, 2002).

The two oldest freestyle techniques are the marathon and V-skate. They incorporate a lateral pushing action with one ski while the opposite ski maintains a forward glide. In marathon skate style one ski always remains on the track while the other ski continuously pushes off with a double-poling action. This style requires classical tracks, which are not needed in the V-skate. During the V-skate the legs alternate from side to side with lateral strokes. Double-poling every other or every kick, and no poling can be used (Eisenman et al., 1989; Smith, 2002).

In cross-country skiing, fatigue may be caused by energy depletion, metabolite accumulation, inadequate oxygen delivery or disturbances of homeostatic functions, or it may be of neuromuscular origin (Rusko, 2003a). During prolonged skiing (5-11 h) the measured mean heart rate levels were 134-165 beats·min^{-1} (Vuori, 1972). It represented the level of 80 to 91% of the individual maximal heart rate of subjects. Muscle enzyme (CK) activities after 42 to 90 km of skiing were minor in subjects under 30 years, but there was found to be a significant increase in men over 50 years (Vuori, 1972).

2.7. Studies of daily repeated prolonged exertions with men in field conditions

2.7.1. Walking studies

Due to the practical and theoretical interest to understand the effects of repeated exertions several studies (Table 1) have focused on daily repeated walking exercise with men in field conditions. However, all of these studies extended only a limited point of view, e.g., concentration on a few specific physiological variables. Walking distances have varied from 35 to 630 km and follow-up time from two to 42 days. The number of the subjects has varied between 1 to 97 and the oldest subjects have been over 70 years of age.

Shapiro et al. (1973) studied the relationship between maximal aerobic capacity and changes in

Table 1. A summary of the studies of daily repeated prolonged walking exertions with men in field conditions.

Study	Distance (km)	Number of days	Number of male subjects	Measurements
Shapiro et al., 1973	110	2	26	Serum enzymes
Myles et al., 1979	204	6	25	Self-paced work
Roussel and Buguet, 1982	204	6	4	HR during sleep
Ross et al., 1983	35	3	15	Muscle enzymes
Davies et al., 1984	544	6	1	Physiological, haematological and hormonal responses
Marniemi et al., 1984	344	7	10	Biochemical parameters
Greenhaff et al., 1987	148	4	6	Metabolic response
Maughan et al., 1987	148	4	6	Metabolic response
Griffin et al., 1988	148	4	6	Plasma lipoproteins
Hedman, 1988	160	4	39	Pain level
Faber et al., 1992	630	42	11	Plasma lipoproteins
Hellsten et al., 1996	150	7	15	Muscle damage
de Wild et al., 1997	120	4	97	Walking speed

blood enzyme concentrations (creatine phosphokinase, glutamic –oxaloacetetic transaminase, aldolase, creatine, creatinine and sorbitol dehydrogenase) in 26 untrained subjects during a 110 km 2-day march. The highest enzyme elevation appeared in subjects with the lowest maximal aerobic capacity and a moderate elevation in those with high maximal aerobic capacity, and it was suggested (Shapiro et al., 1973) that enzyme elevations were primary related to the intensity of the effort with respect of VO_{2max} of the individual and not to its duration.

Myles et al. (1979) studied 25 infantry soldiers who marched 204 km in six days. The daily walking distances were 34, 34, 34, 30, 30.5, and 38.5 km at an average speed of 6 $km \cdot h^{-1}$ on the first day and at 6.5 $km \cdot h^{-1}$ over the next 5 days. An additional weight (22 to 24 kg) was assigned to each subject to ensure that all worked at the same percentage of his aerobic power (40%). The factor limiting performance for many of the subjects was the condition of their feet as a result of marching on the hard road surfaces (Myles et al., 1979).

Roussel and Buguet (1982) examined the effect of six days of moderate prolonged exercise on nighttime heart rates during sleep in four fit, healthy young men. The length of the march was 34 $km \cdot day^{-1}$ and the speed was 6 $km \cdot h^{-1}$, with an intensity of 35% of individual VO_{2max}. After the exercise period the nighttime heart rates increased by about 10% as compared to the previous control condition, and returned to normal during the five days' recovery period. The increase was apparently not related to changes in body temperature, red blood cell content, sleep patterns, cortical adrenal or thyroid functions. The most likely explanation for the nocturnal tachycardia was related to a probable increased sympathoadrenal activity (Roussel and Buguet, 1982).

In a study by Ross et al. (1983) after one day of severe exercise (not detailed) and two days' walking (15 and 20 km, respectively) serum creatine kinase concentration was seven times higher than the rest level before the exercise.

Davies et al. (1984) studied one male subject during 338 miles (130 h) of continuous walking and subsequent sleep deprivation. Creatine kinase and its isoenzyme levels rose throughout the walk. Catecholamine levels rose throughout the walk, with lager increases being observed in noradrenaline and dopamine. During the post-walk recovery phase, adrenaline concentration remained elevated (Davies et al., 1984).

In a study by Marniemi et al. (1984) ten men hiked 344 km from Jyväskylä to Helsinki over seven days. The daily walking distances were from 36 to 67 km at an average speed of 3.5 $km \cdot h^{-1}$. Estimated energy consumption corresponded to 3.5 $kcal \cdot min^{-1}$ yielding in total about 84 MJ (20 Mcal). During the exercise men were allowed to drink water, mineral drinks, and juices ad libitum. Except for some natural products, no food intake was allowed. Total caloric intake during the hike was about 24 MJ (5,700 kcal) and the sleeping time was 5 $h \cdot night^{-1}$. The body mass and serum protein concentrations of the subjects decreased by about 7%, on average. Serum cortisol in the evening after the daily hiking and plasma noradrenaline concentrations were significantly increased and serum testosterone levels decreased, reflecting the immediate daily response to the combined fasting and hiking. Hormonal stress adaptation was reached in three days. Decreased testosterone levels indicated the involvement of the LH-testis pathway (Marniemi et al., 1984).

Greenhaff et al. (1987), Maughan et al. (1987), and Griffin et al. (1988) studied the metabolic responses to prolonged walking on four consecutive days in fed and fasted men. Six healthy men walked 37 km per day on two occasions one month apart; during one walk they consumed a high carbohydrate (CHO) diet and during the other walk an isocaloric low CHO diet. Each day's walking accounted for about 50% of total energy expenditure and the workload was equivalent to 17±1% of VO_{2max}. The first day of each walk demonstrated that the pattern of substrate mobilisation in response to this type of exercise is highly reproducible. Circulating glucose, lactate, insulin, and triglyceride concentrations remained essentially unchanged; alanine fell progressively and glycerol, free fatty acids and 3-hydroxybutyrate rose progressively. Very low-density lipoprotein cholesterol decreased and high-density cholesterol increased when the subjects consumed a mixed diet. The results indicated that even in the overnight fasted state, substrate mobilisation during prolonged low intensity exercise is markedly influenced by the composition of the preceding diet.

Hedman (1998) studied the treatment of feet abrasions with a hydrocolloid dressing in a military unit during intensive marching. Abrasions were mostly (54%) located in the heel region, under the front foot pad (19%), on the sides of the food (14%), and on the toes (10%). After treatment, pain relief was good in 92% and moderate in 8% of those who initially had severe (28%) or moderate (64%) pain.

Faber et al. (1992) studied the effect of prolonged low intensity hiking over a period of six weeks on plasma lipids in 11 men. The subjects walked an average of 15 km per day including resting days. They completed a seven-day estimated dietary record before and during the expedition. The authors concluded that increased physical activity during a hiking expedition together with drastic dietary changes (less protein and fat, and more carbohydrates as compared to their habitual intake) and weight loss (73.8 to 68.2 kg) result in significant decrease in mean plasma total cholesterol level (Faber et al., 1992).

Hellsten et al. (1996) investigated the effect of seven days of strenuous (150 km) marching exercise on xanthine oxidase and insulin-like growth factor in skeletal muscles in 15 men. They observed an elevated expression of xanthine oxidase, insulin-like growth factor immunoreactivity and plasma creatine kinase activity after the exercise. They suggested that the increases resulted from cellular damage.

De Wild et al. (1997) studied 97 men over 70 years old who completed the 1993 Nijmegen Four-Day long-distance March (30 km $\cdot$ day^{-1} on four consecutive days). The mean velocity was 5 km $\cdot$ h^{-1}, mean relative exercise intensity was 52% of VO_{2max} and average heart rate 70% of HR_{max}. VO_{2max} was the most important predictor of the variance in self-selected velocity.

2.7.2. Cross country skiing studies

There are only three studies of daily repeated prolonged skiing exertions with men in field conditions (Table 2).

Vuori et al. (1979) studied plasma catecholamine concentrations and their responses to short-term physical exercise during and after a six-day ski-hike. Shephard (1991) has reviewed the findings from the 91 days transpolar ski-trac, which are described also in Aidaraliyev and Maximov's (1990), Booth et al.'s (1990), and Panin's (1990) proceedings. Fellmann et al. (1992) investigated the interrelationships between pituitary-adrenal hormones and catecholamines during a 6-day Nordic ski race at 1,120-1,230 m above sea level. They obtained the blood samples before and after each day's racing.

In the study of Vuori et al. (1979) the basal noradrenaline plasma levels were increased during the first days of a ski-hike. However, in four days, a plateau was reached. The fluctuations in adrenaline concentrations were in the same direction, although not as striking as those in noradrenaline. Changes in dopamine concentrations were negligible.

In Shephard's study (1991) strength increased, body fat decreased by 5% and aerobic power showed an anomalous decline over the transpolar ski-trek.

Fellmann et al. (1992) found different control mechanisms for hormones of the pituitary-adrenal axis and catecholamines.

Table 2. A summary of the studies of daily repeated prolonged skiing exertions with men in field conditions.

Study	Distance (km)	Number of days	Number of male subjects	Measurements
Vuori et al., 1979	260	6	17	Hormones
Shephard, 1991	1 730	91	13	Polar stress
Fellmann et al., 1992	323	6	11	Hormones

Table 3. A summary of the studies of daily repeated prolonged running exertions with men in field conditions.

Study	Distance (km)	Number of days	Number of male subjects	Measurements
Sanders and Bloor, 1975	79	5	3	Enzyme activities
Dressendorfer et al., 1981	500	20	12	Hematologic factors
Wade et al., 1981	500	20	10	Renal function and regulation
Dressendorfer et al., 1982	500	20	12	Plasma mineral levels
Wade et al., 1982	500	20	12	Urinary abnormalities
Dressendorfer and Wade, 1983	500	20	12	Muscular overuse syndrome
Schürmeyer et al., 1984	1 100	20	5	Hormonal changes
Dressendorfer et al., 1985	500	20	12	Morning heart rate
Pestell et al., 1989	1 000	8	4	Biochemical and hormonal changes
Dressendorfer and Wade, 1991	400	15	19	Plasma steroid levels and leg muscle fitness
Dressendorfer et al., 1991	129	7	10	Aerobic performance and tissue damage
Raschka et al., 1994a; 1994b; 1995	1 000	20	42	Serum enzyme and hormones
Höchli et al., 1995	600	30	6	Structure of skeletal muscle
Oksa et al., 1995	69	5	7	Heart rate
Bishop and Fallon, 1999	6 222	6	16	Injuries
Fallon and Bishop, 2002	6 222	6	7	Haematological variables

2.7.3. Running studies

Most of the studies about the responses to daily repeated prolonged exercise during a specific effort concern running (Table 3), however, none of them focus on mood.

Sanders and Bloor (1975) measured heart rate, rectal temperature, haematocrit, plasma hemoglobin, creatine phosphokinase (CPK), glutamic-oxaloacetatic and glutamic-pyruvic transaminases, lactate dehydrogenase (LDH), adenylate kinase (AK), and lactate and pyruvate before and after exercise during five consecutive days of distance running. Significant increases in heart rate and rectal temperature were unrelated to enzyme levels. Pre-exercise CPK levels rose progressively during the five days exercise period and post-exercise levels were significantly greater than pre-exercise levels on each running day but were unrelated to the severity of the exercise. LDH and AK levels did not change with the exercise stress. They (Sanders and Bloor, 1975) suggest that CPK is a sensitive index of exercise stress in well-conditioned runners and elevated CPK and AK levels in such a runners represent physiological responses.

Dressendorfer et al. (1981), Wade et al. (1981), Dressendorfer et al. (1982; 1985), and Dressendorfer and Wade (1983) have studied marathon runners during a 20-day Great Hawaiian Footrace on days 2, 5, 8, 13, 14, 17, and 20. The participants ran every day, except for a 70-hour rest period following the run on the tenth day till the morning of the 13th day. Dressendorfer et al. (1981) found decreased red blood cell counts and haemoglobin levels after long-distance running that they called “sport anemia”. Wade et al. (1981) studied the renal function, aldosterone, and vasopressin excretion and their data suggested that in response to repeated long-distance running normal fluid balance is regained within 12 hours. Dressendorfer et al. (1982) measured the plasma mineral levels and found no tendency of persistent reduction over the 20 day period. Wade et al. (1982) found no urinary abnormalities (proteinuria, haematouria or cylinduria) during the Great Hawaiian Footrace. Dressendorfer and Wade (1983) measured indicators of muscular injury during the race and found elevated serum creatine kinase levels, mild-to-moderate thigh muscle soreness or stiffness, and reduced thigh circumference. Dressendorfer et al. (1985) found slightly reduced morning heart rates after the first week of running but thereafter morning heart rates increased progressively. Blood pressure, oral temperature, body weight, sweat loss, and blood glucose, lactate, insulin levels, and cortisol levels were not related to the increase in morning heart rate.

The impact of a 20-day run (from the Baltic Sea to the Alps) on pituitary, testicular, adrenal and thyroid hormones has been investigated on the first, fifth, ninth, 14th and 19th day (Schürmeyer et al., 1984). Results showed that adrenal and thyroid function soon adapted to the daily strain. Testosterone levels were markedly decreased throughout the 20 days while LH levels remained unchanged.

Pestell et al. (1989) have studied the biochemical and hormonal responses to a 1,000 km ultra marathon. They analysed serum catecholamine, cortisol, and adrenocorticotrophic and growth hormone (GH) levels after the eight day race and found a significant increase in cortisol, prolactin and GH.

Dressendorfer and Wade (1991) studied the effects of a 15-day race around the Hawaiian islands of Oahu and Maui. Race distances varied from 15 to 34 km, averaging 26.7 km·day^{-1}. Plasma testosterone, adrenal steroid and cortisol levels were measured, and four field tests for leg muscle fitness were used. Testosterone decreased 31% and the ratio of cortisol to testosterone 83% but the test scores for leg power did not change.

Dressendorfer et al. (1991) examined the effects of 7 consecutive days of prolonged running on aerobic performance and biochemical markers of muscle and red blood cell damage in moderately fit men, who jogged for 2 h·day^{-1}; nearly eight times their regular weekly training volume. All subjects experienced leg muscle soreness, especially in the thigh region, after three days until the end of the race. There was a 6-fold elevation in serum enzyme (CK, myoglobin) levels after the fifth day.

Raschka et al. (1994a; 1994b), and Raschka et al. (1995) examined the changes of hormone, and serum enzyme values during an ultra long distance run of 1,000 km. They found decreased insulin, FSH and LH concentrations after the exercise (Raschka et al., 1994a; Raschka et al., 1995). The highest enzyme activities were found after the third day (Raschka et al., 1994b).

Höchli et al. (1995) studied the loss of oxiadative capacity after an extreme endurance Paris-Dakar foot-race. They took muscle biopsies from musculus vastus lateralis before and after the race and analysed fiber size, capillarity and muscle ultrastructual composition. Body fat, thigh cross-sectional area and thigh volume showed tendential reduction immediately after the race. Fiber size and capillarity were not affected by the race. Volume density of total mitochondria, and both subsarcolemmal and interfibrillar mitochondria were reduced.

Oksa et al. (1995) recorded the heart rates of seven males participating in a 5 day jogging relay. The jogging speed was controlled at 3.0 m·s^{-1} on average. During the relay the mean heart rate values were 150 beats·min^{-1}, corresponding to 68% VO_{2max}. The jogging time above anaerobic threshold heart rate level was 9% of the total jogging time. The results indicated that even in a leisure oriented jogging event, cardiorespiratory strain can be rather high.

Bishop and Fallon (1999) documented injuries in 16 men during a 6-day track race and compared these injuries with those incurred during other ultra-marathon track and road races, and investigated a characteristic ultra-marathon injury, tendonitis of the ankle dorsiflexors. They reported a total of 36 injuries in 11 competitors. The ankle and knee were the regions most frequently injured and the most common diagnosis was Achilles tendonitis. During the same ultra long distance running Fallon and Bishop (2002) studied the changes in erythropoiesis. There were findings of hemodilution but red cell parameters were relatively unchanged.

2.7.4. Cycling studies

In all studies of daily repeated prolonged cycling exertions with men in field conditions (Table 4.) the subjects were elite cyclists and in only one study the measurements had been done daily containing only heart rate measurements.

Table 4. A summary of the studies of daily repeated prolonged cycling exertions with men in field conditions.

Study	Distance (km)	Number of days	Number of male subjects	Measurements
Saris et al., 1989a	4 000	22	5	Energy expenditure
Saris et al., 1989b	4 000	22	8	Vitamins
Palmer et al., 1994	236	4	5-7	Heart rate
Lucia et al., 1999	4 400	23	8	Heart rate
Lucia et al., 2001	3 518	21	8-9	Hormones
Fernández-Garcia et al., 2002	3 781	21	18	Hormones
Filaire et al., 2002	740	4	12	Hormones, mood and muscle soreness

Table 5. A summary of the studies of daily repeated prolonged swimming exertions with men.

Study	Exercise (type)	Number of days	Number of male subjects	Measurements
Kirwan et al., 1988	Swimming	10	12	Physiological responses
Morgan et al., 1988	Swimming	10	12	Mood and muscle soreness
O'Connor et al., 1991	Swimming	3	22	Cortisol, heart rate and mood

Saris et al. (1989a) looked at food intake and energy expenditure while Saris et al. (1989b) studied the adequacy of vitamin supply during the Tour de France. Energy expenditure values of the cyclists ranged from a mean of 25.4 MJ·day^{-1} to peak values of 32.7 MJ·day^{-1}. The contribution of macronutrients to energy intake was: 62% from carbohydrates, 23% from protein and 15% from fat. No changes over the 22-day period were observed in mineral or vitamin parameters.

Palmer et al. (1994) and Lucia et al. (1999) have monitored heart rate responses during cycling races. On consecutive days Palmer et al.'s (1994) subjects competed in a 16 km individual time trail, a 110 km mass-start road race, a 5.5 km individual hill climb, and a 105 km mass-start road race. Despite similar racing speeds, the heart rate responses to the longer mass-start races were reduced. Lucia et al. (1999) evaluated the heart rate response to professional road cycling during a 3-week Tour de France (4 400 km) competition as an indicator of exercise intensity. They used two reference heart rates (corresponding to the first and second ventilatory thresholds) to establish three phases of exercise intensity. The relative contributions of each phase were 70%, 23%, and 7%.

Lucia et al. (2001), Fernández-Garcia et al. (2002), and Filaire et al. (2002) have evaluated the hormonal responses during cycling races. Lucia et al. (2001) measured morning urinary levels of 6-sulphatoxymelatonin, and morning serum levels of testosterone, follicle stimulating hormone, luteinizing hormone, and cortisol before the competition, and at the end of each week during the three weeks Tour de France. Urine samples were also evaluated in the evening at the end of each of the three weeks. They found decreased 6-sulphatoxymelatonin, cortisol and testosterone levels after consecutive days of intense, long-term exercise.

Fernández-Garcia et al. (2002) studied the response of sexual and stress hormones of male professional cyclists during the three weeks of Vuelta a España. They found a decrease in the plasma testosterone and cortisol, but no changes in LH or FSH during the race.

Filaire et al. (2002) measured hormones during the four days of increased training (+187%) in cyclists. They assessed the overall mood and muscle soreness levels, as well. A decrease in testosterone and an increase in cortisol levels were observed but the overall mood and muscle soreness were not affected by the training.

2.7.5. Swimming studies

Table 5 provides a summary of the studies of daily repeated prolonged swimming exertions with men in field conditions.

Kirwan et al. (1988) examined physiological responses to ten successive days of intensive training in competitive swimmers. Morning resting heart rates, and blood pressure were measured daily. Cortisol, catecholamines, creatine kinase, glucose, lactate and plasma volume were determined in the beginning, middle and at the end of the training period. Serum cortisol and creatine kinase were elevated, haemoglobin and haematocrit increased, with no other significant changes observed.

Morgan et al. (1988) studied 12 male swimmers psychologically before, during, and after ten days of increased training. Daily training distance was increased from 4,000 to 9,000 m · day^{-1}, and intensity was maintained at 94% of VO_{2max}. They found significant increases in the ratings of muscle soreness, depression, anger, fatigue, and global mood disturbance, along with a reduction in the sense of general well-being.

O'Connor et al. (1991) studied the physiological effects of 3 days of increased training in swimmers. Training volume of 22 male college swimmers was increased from 8,800 to 12,950 m·day^{-1}. Salivary cortisol, heart rate, stroke mechanics, as well as overall and local ratings of perceived exertion (RPE) were measured in conjunction with the two swim tests. Mood states and ratings of perceived muscle soreness were assessed daily. Elevations of fatigue, mood state data, and muscle soreness levels occurred in association with the increased training.

2.7.6. Military studies

All studies (Table 6), where the responses to prolonged physical strain during military training

Table 6. A summary of the studies of daily repeated prolonged military exertions with men in field conditions.

Study	Exertion (type)	Number of days	Number of male subjects	Measurements
Aakvaag et al., 1978a	Combat course	5	8	Testicular function
Aakvaag et al., 1978b	Combat course	5	22	Hormonal changes
Opstad et al., 1978	Combat course	4/5	44	Performance, mood, clinical symptoms
Opstad and Aakvaag ,1982	Ranger training course	5	11	Hormonal changes
Opstad ,1994	Military training course	5	10 18	Hormonal changes and mental performance

courses have been followed, include sleep deprivation or low energy diet, or both.

Aakvaag et al. studied the effect of prolonged physical and psychological stress on the testicular function during a combat course; high caloric consumption with limited caloric intake, lack of sleep, strong discipline with occasional irrational punishment (1978a), and the endocrine response (1978b). They found a marked suppressive effect on plasma testosterone and no changes in LH or FSH levels.

Opstad et al. (1978) studied the shooting, command memory and reaction time task, visual vigilance, code and sorting test, and mood in men exposed to prolonged, severe physical work and sleep deprivation during four and five day combat courses. The subjects were tested and clinically examined each morning. They observed substantial impairment in all tests, as well as clinical symptoms toward the end of the courses.

Opstad and Aakvaag (1982), and Opstad (1994) studied the hormonal responses during military training course involving heavy and continuous physical activities with almost total lack of food (less than 1,500 kcal·day^{-1}) and sleep. Testosterone (Opstad, 1994; Opstad and Aakvaag, 1982) was strongly reduced and cortisol increased (Opstad, 1994) during the course. Opstad (1994) investigated the mental performance, as well, which decreased.

3. AIMS OF THE STUDY

The aim of this work was to examine the magnitudes and time courses of the physiological and psychological responses to various (intensity, duration, mode/type) daily repeated prolonged exercise. The specific problems were to describe in healthy men the responses of the cardiovascular (Study 1, 3, 5), autonomic nervous (Study 3, 5), musculoskeletal (Study 1, 3, 5), and endocrine systems (Study 1, 2, 4, 6), and mood states (Study 2, 3, 5).

The focus was on the quantification of possible disadvantages caused by daily repeated physical activity differing in intensity, duration and mode/type.

Acute cardiorespiratory response was measured by the heart rate during the exercise. Responses of the autonomic nervous system were estimated by measuring the heart rates in an orthostatic test. Musculoskeletal responses were estimated by measuring the perceived pains, flexibility, functional strength, use of elastic energy and oedemic changes of the lower extremities. Hormonal responses were assessed using the urinary excretion of catecholamines, and serum cortisol, testosterone and gonadotropins. The mood state was evaluated using the Profile of Mood States (POMS) test.

The hypothesis of this study was that prolonged strenuous exercise would decrease the functional capacity of the lower extremities, disturb the balance of the autonomic nervous system and the secretion of hormones from the adrenal cortex and pituitary-testicular axis, also negative mood states were postulated.

4. METHODS

4.1. Subjects

A total of 28 healthy physically active fit men volunteered for these studies after they had been fully informed and their signed informed consent was obtained. Three of the subjects were involved in two different study designs (Study 3-4 and 5-6). In the first marching studies (Study 1-2) the subjects were army officers representing the Finnish Military Sports Federation. In the two other marching studies (Study 3-4) nine subjects were army officers representing the Finnish Military Sports Federation and six were cadets from National Defence College; First Degree Division (Military Academy, Finland).

Table 7. Physical characteristics of the subjects (Study 1-6). Data are means (± SD).

Study	1, 2 (n=6)	3, 4 (n=15)	5, 6 (n=10)
Age (years)	36.6 (7.7)	27.1 (3.8)	34.8 (9.7)
Height (m)	1.76 (.08)	1.81 (.06)	1.82 (.05)
Mass (kg)	74.4 (8.1)	79.4 (5.3)	76.1 (6.6)
Body mass index	23.9 (2.2)	24.3 (1.7)	23.0 (1.5)
Body fat (%)	13.7 (3.5)	12.2 (4.7)	10.0 (4.2)
TR ($h\cdot week^{-1}$)	9.3 (4.7)	6.0 (2.5)	9.2 (4.1)
Cooper (m)	3 088 (360)	3 177 (175)	
VO_{2max} ($l\cdot min^{-1}$)		4.7 (.6)	4.9 (.6)
VO_{2max} ($ml\cdot kg^{-1}\cdot min^{-1}$)		62 (5)	66 (6)
RQ_{max}		1.01 (.05)	1.04 (.07)
HR_{max} ($beats\cdot min^{-1}$)		183 (12)	182 (12)

TR= Training background during 10 weeks preceding the exercise, Cooper= Best result in Cooper's 12-minute running test within the last two years.

In the skiing studies (Study 5-6) the subjects were three army officers and seven recreational endurance athletes. None of the subjects were taking any prescribed medication or had a history of cardiovascular, renal or skeletal muscle diseases. Their level of physical fitness was high and body mass was in normal proportion to their height, and they had relatively low subcutaneous fat content. The subjects of studies 1-2 had, preceding the march, 10 weeks of a common preparatory training program consisting of an average of 9.3h of exercise during 2 to 4 h sessions, and their training background was 414 ± 197 $h\cdot year^{-1}$. This training amount did not differ from their habitual physical activity and it was performed almost solely by walking. The subjects of studies 3-6 had no specific preparatory training program for the events. Some physical characteristics of the subjects are summarized in Table 7.

4.2. Study designs

The data of these short-term follow-up (reversal) designs (Cook and Campbell, 1979; Thomas and Nelson 1990, p. 311-313) were collected in 1993 (Study 1, 2) and 1994 (Study 3, 4) during the "International Four-Day Long-Distance March" in Nijmegen, The Netherlands, and in 1995 during the Finlandia Ski Race (Study 5, 6). The track profile of the Finlandia Ski Race is presented in Figure 1. Characteristics of the events are summarised in Table 8. The Ethics Committee of the University of Jyväskylä, Finland and the Defence Staff, Finnish Defence Forces, Department of the Health Care approved the arrangements of this study.

The "International Four-Day Long-Distance March" in Nijmegen, The Netherlands is open to both civilian and military participants who march over 40 km on each of the four days. Walking during the march was determined as follows: "moving forward in such a way that the full body-weight has permanent contact with the ground, alternately via the right and the left feet" (Program-Magazine De 4 Daagse, 1994). As the intention of the march was not to cover the total distance within the shortest possible time, the competitive element can be considered to be minimal. Detachments marched together, two abreast. In order to avoid dehydration and energy deficit, water and standard food (soup, meat, potatoes, bread, salad, dessert) were provided. At the three main resting stops soft drinks, milk and snacks were for sale. The surface of the routes was mostly hard (asphalt or stone) and the route was almost totally flat, except on the third day. The average air temperature during the marches in 1993 almost totally flat, except on the third day. The average air temperature during the marches in 1993

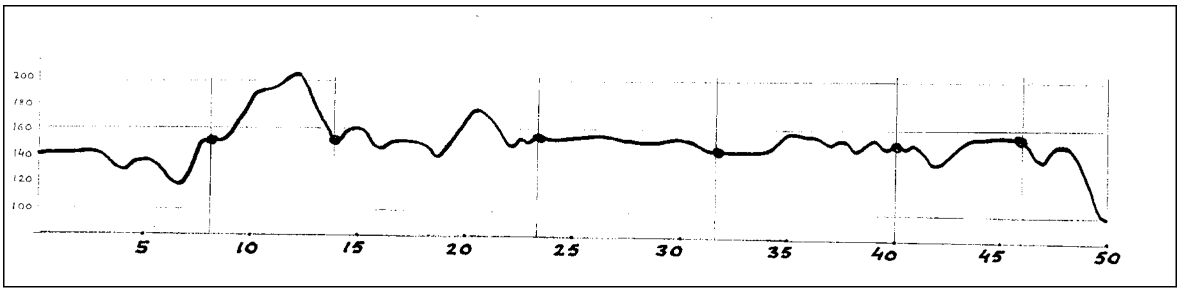

Figure 1. The track profile of the Finlandia Ski Race.

Table 8. Characteristics of the daily repeated prolonged exercises (Study 1-6).

Day	1	2	3	4	Total	Mean
Mode						
1-2	Walking	Walking	Walking	Walking		
3-4	Walking	Walking	Walking	Walking		
5-6	Skiing	Skiing				
Duration (h)						
1-2	7.1	8.0	8.4	10.3	33.8	8.5
3-4	7.3	8.2	8.3	8.8	32.4	8.1
5-6	3.2	2.7			5.9	3.0
Intensity (HR% of maximum)						
3-4	61 (±3)	58 (±3)	60 (±5)	57 (±5)		59 (±3)
5-6	87 (±7)	86 (±7)				87 (±7)

and 1994 was 12 to 15°C early in the morning and 18 to 30°C at noon. The subjects wore ordinary army uniforms and combat boots (1,400 g). The last 10-km of the fourth day march was walked without the backpack because of the final parade.

The walkers were required to carry a backpack weighing at least 10 kg. Apart from the participants, only one support person on bicycle was permitted per detachment. Night rest in tents commenced between 08.00 - 10.00 p.m., and ranged from 5 to 7 h in length. Consumption of food and beverages was not limited. Medical care was provided through subjects' self-medication and by the organizers. No exercise was performed two days before, or one week after the march.

In studies 5-6 the distance skied daily was 50 km on both days, starting at 11:00 a.m. On the first day the skiing technique to be used was classical and on the second free. The weather conditions were similar on both days: air temperature +1°C and cloudy. In order to avoid dehydration effects and an energy deficit, water and small snacks were provided during the event. One of the subjects (n=10) had to leave the study because of a fall.

4.3. Measurements

The protocol of the physiological measurements and collections are shown in Tables 9-11. The measurements consisted of body mass, heart rate during the exercises, orthostatic test, perceived pain and functional capacity of lower extremities. Blood samples were also taken and urine was collected during the study. The mood state was evaluated using the Profile of Mood States (POMS) test (McNair et al., 1971).

The best result of subjects in the Cooper's 12-minute running test (Cooper, 1968) within the last two years was used to evaluate the endurance capacity of the subjects in studies 1-4. Maximal

Table 9. The protocol of the physiological measurements, collections and questionnaires during four days of prolonged walking (Studies 1-2).

Day/March	Pre7	1.		2.	3.	4.	Rec1
		Pre	Post	Post	Post	Post	
Body mass	X						
Heart rate during exercise		----		----	----	----	
Pain	X	X	X	X	X	X	
Functional capacity of lower extremities	X	X	X	X	X	X	
Blood sample:							
creatine kinase, cortisol and testosterone	X	X	X	X	X	X	X
Urine collection:							
during march		-----		----	----	----	
during rest		----	----	---- ----	---- ----	---- ----	----
POMS	X	X	X	X	X	X	

Pre7 = one week before, Pre = in the morning before and Post = in the evening after each march, and Rec1 = one day after the last march. ---- Continuous collection.

Table 10. The protocol of the physiological measurements, collections, and questionnaires during four days of prolonged walking (Study 3-4).

Day/March	0	1.		2.		3.		4.		Rec1	Rec9
		Pre	Post	Pre	Post	Pre	Post	Pre	Post		
Body mass		X	X	X	X	X	X	X	X		
Heart rate during exercise		----		-----		-----		-----			
Orthostatic test		X		X		X		X		X	
Pain	X		X		X		X		X		X
Functional capacity of lower extremities	X								X		
Blood sample:											
total protein, cortisol, testosterone, LH, and FSH	X	X	X	X	X	X	X	X	X	X	X
POMS	X		X		X		X		X		X

0 = the day before, Pre = in the morning before and Post = in the evening after each march, and Rec1 = one day and Rec9 = nine days after the last march. ---- Continuous collection.

oxygen uptake and the related variables were measured during an incremental uphill walking test on a treadmill to subjective maximal effort from seven subjects of the studies 3-4 and all subjects (n=10) of studies 5-6. Expired air was collected and analysed continuously with an automatic metabolic analyser (Beckmann MMC, Beckman Instruments, Illinois, USA) for successive 30-second periods. The electrocardiogram was monitored continuously and heart rate was recorded at the end of each two-minute stage.

Body mass was measured, and the percentage of body fat was estimated from the thickness of four skinfolds (Durnin and Rahaman, 1967). Body mass index (BMI) was calculated according to the height and mass of the subjects (Keyes et al., 1972).
Alcohol consumption and the use of analgesic drugs during the exercises were questioned in studies 1-4.

4.3.1. Cardiorespiratory and autonomic nervous system

Each subject wore a heart rate monitor (Sport Tester PE 3000, Polar Electro OY, Kempele, Finland). Heart rates were recorded at 60-s intervals during the exercises. Orthostatic heart rate recordings (Study 3, 5) were taken firstly in the supine position after the night sleep and secondly at 30 seconds after getting up by a heart rate monitor (Sport Tester PE 3000, Polar Electro OY, Kempele, Finland). Heart rates were recorded at 15-s intervals.

4.3.2. Musculoskeletal system

Responses to the musculoskeletal system were evaluated by questions on perceived pain, assessment of functional capacity of lower extremities (the range of movement, muscle strength and the use of elastic energy, circumferences), and

Table 11. The protocol of the physiological measurements, collections, and questionnaires during two days of prolonged skiing (Study 5-6).

Day	0	1		2		Rec7
		Pre	Post	Pre	Post	
Body mass	X	X	X	X	X	
Heart rate during exercise		----		----		
Orthostatic test		X		X		
Pain	X		X		X	X
Functional capacity of lower extremities	X				X	
Blood sample:						
creatine kinase, cortisol, testosterone, LH, and FSH	X	X	X	X	X	X
POMS		X	X		X	X

0 = the day before, Pre = in the morning before and Post = in the evening after each race, and Rec1 = one day and Rec9 = nine days after the last race. ---- Continuous collection.

measurements of creatine kinase activity (CK) in serum (Study 1, 5).

Intensity of overall perceived pain was assessed using a visual analogue scale (VAS) (Haynes and Perrin, 1992). The scale was a 10-cm horizontal line ranging from "no pain" (on the far left) and "unbearable pain" (on the extreme right). The following descriptors were spread at even intervals along the line from left to right: "dull ache", "slight pain", "more slight pain", "painful", and "very painful". Pain was quantified by measuring the length of the line from the extreme left of the scale to the subject's mark. The location of pain in the lower limbs (muscle, joint, feet) as well as other pains, abrasions and blisters were indicated on body charts and pain intensity was estimated with a score of descriptors ranged from 0 to 6 with terms alike in the VAS.

To assess the flexibility of the lower extremities, the range of movement (ROM), was measured with a standard plastic goniometer (Wang et al., 1993). The subjects were instructed to relax the muscles during the procedure. The tightness of the knee flexors (KF) was determined by passive hip flexion with the knee extended. Subjects were positioned supine on a table with their opposite thigh and the knee to be measured stabilised. The goniometer was placed with the stationary arm parallel to the midline of the trunk, the moving arm along the lateral midline of the thigh, and the axis over the superior half of the greater trochanter. The leg to be measured was raised to the point in the range where a small amount of pelvic movement was elicited by the investigator. The tightness of the knee extensors (KE) was measured by hip extension. Subjects were positioned supine on the table with the leg to be measured hanging over the table. The opposite hip and knee were flexed to the point where the investigator palpated that the subject's lumbar spine was flat on the table. The subjects were instructed to maintain this hip and knee position with the fingers of both hands interlocked over the anterior tibia to assist in the maintenance of the posterior pelvic tilt. The goniometer was placed with the stationary arm parallel to the lateral midline of the thigh, the moving arm along the lateral midline of the tibia, and the axis over the lateral side of the knee joint. The tightness of the hip flexors (HF) was measured with the hip extended. The procedure was the same as for the measurement of the knee extensors, except that goniometer placement was the same as that for the measurement of the knee flexors.

Functional muscle strength and the use of elastic energy of the lower extremities were evaluated according to Komi and Bosco (1978) on an electric contact mat (Digitest OY, Muurame, Finland) with maximal voluntary vertical jumps. The first jump, called a squat jump (SJ), was performed from a static semisquatting position (a knee angle of 90 degrees) with no allowance for preparatory counter-movement. In a second jump, called a counter-movement jump (CMJ), the subject started from a standing position with a preliminary counter movement followed by an immediate jump upwards. The isolated jumps (SJ, CMJ) were repeated three times and the average flight time was calculated.

Oedemic changes of the lower extremities were estimated by measuring the greatest circumference of the calves (CC), as well as circumference of the thighs (CT) 25 cm above the middle part of the patella.

4.3.3. Urinary collection and catecholamine analyses

All daily urine was collected in study 1. Urine prior to the first march, during each march and between the marches was collected separately. Urinary volume and collection time were measured and used to estimate urine excretion. Four ml of 6 M hydrochloric acid was added to the urine to decrease pH, and the samples were kept frozen at -20°C until assayed within six months at Department of Forensic Medicine, University of Oulu. Urinary catecholamines were purified by an Al_2O_3-extraction procedure. The catecholamines were extracted at a pH of 8.6 from 25 µl urine into 30 mg Al_2O_3 with 3.4 -dihydroxybenzylamine hydrobromide as an internal standard. After washing four times with 2 ml H_2O, the catecholamines were released into 100 µl 0.2 M $HClO_4$ - solution. A high pressure liquid chromatograph with an electrochemical detector (Esa Couluchem Multi- Electrode, model 5100 A, ESA, Inc., Chelmsford, MA, USA) was used for the determination of free noradrenaline and adrenaline. The column was an Esa Catecholamine HR-80 and a mobile phase Esa Cat-A-Phase reagent. The flow rate was 1.0 ml·min^{-1}. The ratio of the peak height of each catecholamine standard to the peak height of the internal standard was used as the basis for concentration calculations.

4.3.4. Blood samples and biochemical analyses

In studies 1-2 blood samples were taken in the afternoon (between 1:30 and 5:30 p.m.), except PreI sample, which was taken in the morning (between 2:00 and 4:30 a.m.). In studies 3-4 blood samples were taken at 11 time points in time and in the same order with respect to each subject on each day (variation ± 1 h), following a systematic time pattern: 1) a day before the first exercise session between 2:00 and 5:00 p.m. (0 sample), 2) in the morning (between 2:00 and 5:30 a.m.) within 2 hours preceding each walking session (Study 1 - 4), 3) in the afternoon (between 2:30 and 6:30 p.m.) within 60 min after each walking session, and 4) one and nine days after the last day of the walk (between 7:00 and 8:00 a.m. and between 1:00 and 2:00 p.m., respectively). In studies 5-6 blood samples were taken between 9:45 and 10:15 a.m. and between 1:30 and 3:00 p.m. after both event, and after one week's recovery at 2:00 p.m. Blood was drawn from the antecubital vein. Serum was separated and kept frozen at -20ºC until assayed.

Serum creatine kinase (CK) activity (Study 1, 5) and total protein concentration (Study 4, n=10) were analysed according to standard laboratory methods: Serum creatine kinase (Boehringer, Mannheim, Germany) and protein (Reagena, Kuopio, Finland) in LIKES-Research Center, Jyväskylä. The normal value of CK provided by the kit manufacturer for men was CK µ190 $U \cdot l^{-1}$.

Concentrations of serum cortisol and testosterone were measured using radioimmunometric assay (RIA) kits purchased from Farmos Diagostica (Turku and Oulunsalo, Finland) in LIKES-Research Center, Jyväskylä (Study 1) and in Research Institute of Military Medicine, Helsinki (Study 4, 6). Concentrations of serum immunofluorometric LH and FSH were measured using time-resolved immunofluorometric assay (IFMA) kits (DELFIA hLH Spec, DELFIA hFSH) provided by Wallac OY (Turku, Finland) in Department of Physiology, University of Turku (Study 2, 4, 6). The intra- and inter-assay coefficients of variation were below 5 and 10%, respectively. The reference ranges for men provided by the kit manufacturer were as follows: cortisol 244 - 727 $nmol \cdot l^{-1}$ between 7:00 and 10:00 a.m. and 110 - 418 $nmol \cdot l^{-1}$ between 3:30 and 5:30 p.m., testosterone 9 - 38 $nmol \cdot l^{-1}$, LH 1.0 - 8.4 $IU \cdot l^{-1}$, and FSH 1.0 - 10.5 $IU \cdot l^{-1}$ In study 6 one subject with resting LH value lower than the reference range was excluded when calculating the means of LH and the standard deviations of the means.

4.4. Mood states

Mood states were assessed with the Profile of Mood States (POMS) questionnaire "How you have been feeling today?" (McNair et al., 1971), which measures six identifiable moods of affective states: Tension-Anxiety (T), Depression-Dejection (D), Anger-Hostility (A), Vigour-Activity (V), Fatigue-Inertia (F), and Confusion-Bewilderment (C). A total mood disturbance (TMD) score was also obtained from the POMS by summing the scores across all six factors (weighting V negatively), and adding a constant of 100 to eliminate negative values. The higher the TMD score, the worse is the mood. Possible ranges of the POMS raw scores are as follows: Tension-Anxiety 0-36, Depression-Dejection 0-60, Anger-Hostility 0-44, Vigor-Activity 0-32, Fatigue-Inertia and Confusion-Bewilderment 0-28. Factor T is defined by adjective scales descriptive of heightened musculoskeletal tension. The defining scales include reports of somatic tension, which may not be overtly observable (Tense, On edge), as well as observable psychomotor manifestations (Shaky, Restless). Factor D appears to represent a mood depression accompanied by a sense of personal inadequacy. It is best defined by scales indicating feelings of personal worthlessness (Unworthy), futility regarding the struggle to adjust (Hopeless, Desperate), a sense of emotional isolation from others (Blue, Lonely, Helpless, Miserable), sadness (Sad, Unhappy), and guilt (Guilt, Sorry for things done). Factor C appears to represent a mood of anger and antipathy towards others. Factor V is defined by adjectives suggesting a mood of vigorousness, ebullience, and high energy. It is negatively related to the other POMS factors. Factor F represents a mood of weariness, inertia, and low energy level and factor C appears to be characterized by bewilderment and muddleheadness. In study 2 (n=5) mood states were measured one week prior and immediately before the first march, within 1 hour after each march session. In study 3 (n=8) mood states were measured the day before the first march, and during the evening of each day of marching and nine days after the last march. In study 5 (n=6) mood states were measured one day before the event, daily after the event, and after a one-week recovery period.

4.5. Statistics

The results are presented as means ($\pm$ SD or SE). Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS, Version 9.0 for Windows, SPSS Inc., USA). A one-way ANOVA with repeated measures was employed to examine the response to repeated exercise. In the case of a significant repeated exercise response in ANOVA, the other time points were compared to the baseline, further analysis was then performed with the Student's t-test for matched-pairs. A separate ANOVA for morning and afternoon hormone samples (Study 4) was used because of the circadian rhythm. An *a priori* p-value of < 0.05 was selected to indicate statistical significance.

5. RESULTS

The main findings from the experiments are presented below. For more details consult the original papers (Study 1-6).

5.1. Physiological responses to daily repeated prolonged exercise

5.1.1. Cardiovascular system

The average heart rate during walking was 109 ± 9 (Study 1-2) and 108 ± 6 (Study 3-4) while during skiing it was 157 ± 13 beats·min^{-1} (Study 5-6). The mean heart rate level during walking was 57-61% (Study 3-4) and skiing 86-87% (Study 5-6) of maximal rate (Table 8).

5.1.2. Autonomic nervous system

Morning heart rate in the supine position increased progressively throughout the marching period being highest (p = 0.042) on the day after the last march compared to the pre-exercise control (Study 3). Heart rate in the standing position was first elevated ($p = 0.045$) on the morning of the second day, and a highly significant rise ($p = 0.006$) was seen before the fourth march compared to the pre-march control. The difference between the standing and supine heart rates increased before the last march and the day after, respectively, compared to the pre-march control ($p = 0.001$ and 0.003).

There were no significant differences in the supine and standing heart rates or in the difference between them before the first (Pre I) and second (Pre II) skiing days (Study 5).

5.1.3. Musculoskeletal system

Summary of the musculoskeletal responses to daily repeated prolonged exercise is presented in Table 12.

5.1.3.1. Perceived pain

The total pain index already increased by the first day of marching, and reached its highest values on the third and fourth day (Study 1, 3). After the first march, pain was mainly (50-66%) focused on the musculature of the calves, thighs and buttocks. The intensity of the muscle pain varied from one to three (out of six) ("dull ache" - "more slight pain"). During the last three days, the pain was almost completely (60 to 91%) localised to the feet. The pain intensity of abrasions and blisters of the feet varied from two to six ("slight pain" - "very painful"). Joint symptoms in the lower extremities varied from 25 to 43% of the subjects after the marches (Study 3). Almost all subjects (83-100%) reported pain on the scoring scale “more slight pain“ on days III and IV, which was due to abrasions and friction blisters of the feet (Study 1). "Other" pain was mostly caused by abrasions from the straps of the backpack on the shoulders and the intensity was one ("dull ache") (Study 1, 3).

Before the event skiers experienced no pain. After the first event, however, pain increased ($p = 0.04$) and remained at a similar elevated level ($p = 0.013$) after the second day. After skiing, pain was focused mainly in the neck, shoulders, back and buttocks and the intensity varied from one to three ("dull ache" - "more slight pain"). One week later the perceived pain had disappeared (Study 5).

5.1.3.2. Functional capacity of lower extremities

ROM measurements showed no impairment in the flexibility of the hip flexors, knee extensors or flexors of either leg. The exercise periods did not affect the results gained from maximal voluntary vertical jumps. The circumferences of the calves and thighs remained also unchanged in all studies (Study 1, 3, 5).

5.1.3.3. Serum proteins

On the first and last day of the march serum total protein concentration increased by 4% ($p = 0.02$) after the first march compared with the pre-exercise level (Pre I) and by 3% ($p = 0.04$) compared with the baseline (0) measurement (Study 4). After the final march there was also a 4% increase in serum protein ($p = 0.007$) compared with the pre-session (Pre IV) level.

A highly significant repeated exercise

Table 12. Musculoskeletal responses to daily repeated prolonged exercise (Study 1, 3, 5).

Study	Subjects	Mode of exercise	Overall response				
			Pain	ROM	Jumps	Circumferences	CK
1	6	Walking	↑	0	0	0	↑
3	11-15	Walking	↑	0	0	0	
5	9	Skiing	↑	0	0	0	↑

↑ = significant increase, 0 = no changes

Table 13. Endocrinological responses to daily repeated prolonged exercise (Study 1, 2, 4, 6).

Study	Subjects	Mode of exercise	Response/Day				
			Catecholamines 1. 2. 3. 4.	Cortisol 1. 2. 3. 4.	Testosterone 1. 2. 3. 4.	LH 1. 2. 3. 4.	FSH 1. 2. 3. 4.
1, 2	6	Walking	↑ ↑ ↑ ↑	0 0 0 0	0 0 0 0	0 ↓ ↓ 0	0 0 0 0
4	15	Walking		↑ ↓ ↓ ↓	↓ ↓ 0 0	0 ↓ ↓ 0	0 ↓ ↓ ↓
5	9	Skiing		↑ ↑	↓ ↓	↓ ↓	0 0

↑ = significant daily increase, ↓ = significant daily decrease, 0 = no daily change.

response was seen in serum CK activity ($p < 0.001$) in all studies (1, 5). After the first day's march, CK was increased when compared to the one-week or day before measured baseline ($p = 0.022$ and 0.038, respectively), and remained elevated (mean increase from 400 to 650%, $p = 0.003$-0.043) until the end of the marching period. On the recovery day CK activity returned to control levels. After the first day's skiing race, CK was 62% higher than the pre-race level (203.8 vs. 125.8 $U \cdot l^{-1}$, $p = 0.001$). After the second day's skiing race, CK had increased to 196% above pre-race level (371.9 vs. 125.8 $U \cdot l^{-1}$, $p < 0.001$) and 42% above the level before the second race (371.9 vs. 262.1 $U \cdot l^{-1}$, $p = 0.003$). One week later, CK activity had declined significantly ($p = 0.014$) below the post-race activity.

5.1.4. Endocrine system

Table 13 contains a summary of the endocrinological responses to daily repeated prolonged exercise.

5.1.4.1. Catecholamine excretion

In ANOVA a significant repeated march response was not seen in the urinary excretion of catecholamines (Study 1). The acute response to a single march was seen on the third day when excretion of noradrenaline during the march was significantly increased by 233% ($p = 0.027$) when compared to the exertion during the first march. Further, compared to the preceding night it was 300% ($p = 0.025$). Also the excretion of noradrenaline in the night tended to increase during the experiment being 2.1-fold ($p = 0.08$) during the last night compared to the night prior to the first march. On the fourth marching day there was no more increase when compared to the excretion of the first day ($p = 0.17$).

During the night preceding the first march the urinary excretion of free adrenaline was below the method's detection limit. It increased to 3.2 $nmol \cdot ml^{-1} \cdot h^{-1}$ ($p = 0.018$) during the night prior to the last march. During the first three days the excretion of adrenaline during the march was significantly ($p = 0.02$, 0.40 and 0.001, respectively) greater than the previous rest excretion. In the case of adrenaline the largest individual increase in the daily excretion during the march was 10-fold, occurring during the third 24-h period of the experiment. The difference between the previous rest excretion and march excretion was not significant ($p = 0.09$) after the third day.

5.1.4.2. Serum hormones

In the evening one week and one day prior to, as well as during the first morning of the exercises (Study 1, 2, 4, 6), all hormone concentrations were within the normal range for adult men, except for the LH value in one subject (Study 6).

In the case of cortisol, the early morning value in study 1 was significantly higher ($p = 0.019$) than the afternoon control value. After the second march, cortisol was significantly lower ($p = 0.020$) than the early morning value. As in the case of testosterone, ANOVA showed no statistically significant differences between the afternoon samples in study 1, but in study 4 a highly significant repeated marching response was seen in the morning and afternoon (ANOVA, $p = 0.01$ and 0.0011, respectively). The acute response to a single march on serum cortisol was only seen during the first day when there was a 60% increase (296 vs. 474 $nmol \cdot l^{-1}$, $p = 0.003$) after the first march. After that a downward trend was seen in the afternoon samples (mean decrease from 8 to 19%, $p = 0.09$, 0.34 and 0.22, respectively) compared with the previous Post sample.

During skiing (Study 6) there was a significant response to repeated exercise in serum cortisol levels ($p < 0.001$). An acute response was seen after both events when cortisol increased by 2.2- and 2.6-fold, during the first and second days respectively ($p < 0.001$). One week later (Rec) the C-level had returned ($p = 0.028$) to the Pre I level.

In study 1, during the first morning, the serum testosterone level was significantly higher ($p = 0.030$) than in the afternoon one-week prior the march. After the first, second and fourth day of marching testosterone significantly decreased ($p = 0.029$, 0.049 and 0.010, respective) to less than 80% of the starting value. However, using ANOVA, no statistically significant differences existed between the afternoon samples ($p = 0.5$) in study 1. In study 4 a highly significant repeated marching response was seen in the morning (ANOVA, $p = 0.001$), but not in the afternoon (ANOVA, $p = 0.21$).

In testosterone serum levels a significant difference was seen in study III after the second day of walking when testosterone was reduced by 18% ($p = 0.006$) compared with the morning level for the same day. After the first march, testosterone levels tended to decrease by 15% ($p = 0.06$) from the preceding morning concentration. However, pre- and post-march testosterone levels did not differ significantly on the third and fourth day of the walk ($p = 0.86$ and 0.50, respectively) in study 3, and a plateau was reached by the third day.

A significant decrease due to repeated skiing in testosterone was seen during the two-day's skiing ($p = 0.001$). An acute drop in concentration in response to each exercise session was seen: testosterone level was reduced by over 20% ($p = 0.016$ and 0.002, for the first and second days respectively) compared with pre-race levels. One week later (Rec) the testosterone level was restored ($p = 0.031$) back to the Pre I level.

There was no significant response to repeated marching on serum LH in study 2. Serum LH in study 4 revealed a highly significant repeated march response in the afternoon (ANOVA, $p = 0.0002$), but not in the morning samples (ANOVA, $p = 0.12$). The acute response to a single march on LH was seen after each of the first three days of walking. After the first march there was a slight upward trend (3.9 vs. 5.0 $IU \cdot l^{-1}$, $p = 0.07$) and after the second and third march LH was reduced by 31% ($p = 0.04$ and 0.001, respectively) compared to the level after the first march. After the third march LH was reduced by 37% compared with the pre-march sample ($p = 0.001$). However, after the fourth march the acute response was no longer observed ($p = 0.11$).

In serum LH there was a significant ($P=0.020$) response to repeated skiing (Study 6). LH decreased after the first race by 37% and after the second race by 44% ($p = 0.028$, both).

There was no significant response to repeated marching on serum FSH concentrations in study 2, but in study 4, a highly significant repeated march response on both morning and afternoon samples (ANOVA, $p = 0.01$ and 0.0002, respectively) was found. After the first march there was no acute response ($p = 0.43$). The acute response to a single march in FSH was seen after the last three days of walking. After the second, third and fourth march FSH was significantly lower compared to the concentration the day before the march (0) ($p = 0.02$, 0.02 and 0.03, respectively). Concentration of serum FSH was reduced by 19% ($p = 0.02$) in the morning sample before the fourth march when compared to the morning before the first march.

During skiing (Study 6) there was no significant response to repeated exercise on serum FSH concentrations. After the second race there was a decreasing trend in FSH by 13% ($p = 0.064$, ns.).

5.2. Mood states after daily repeated prolonged exercise

The total mood disturbance score was unchanged during all exercise periods (Study 2, 3, 6).

The responses to repeated exercise (Table 14) were found in Fatigue-Inertia affective state (study 3 $p = 0.02$, study 5 $p = 0.01$). In study 2 the Fatigue-Inertia affective state was the highest after the first and in study 3 after the last march. In the study 5 the Fatigue-Inertia affective state was the highest after the second day of skiing.

6. DISCUSSION

Six, 15, and 10, male subjects were followed in this study during daily repeated prolonged exercises under true field conditions. The subjects were healthy and they marched 163 to 185 km over four days, corresponding to a total of 200,000-250,000 steps (Sekiya et al., 1996) or skied 100 km over two days. The purpose was to describe the responses of cardiorespiratory, autonomic nervous, musculoskeletal and hormonal systems, and mood states after daily repeated acute but non-competitive

Table 14. Fatigue-Inertia affective state responses to daily repeated prolonged exercises (Study 2, 3, 5).

Study	Subjects	Mode of exercise	Day/Response			
			1	2	3	4
2	5	Walking	0	0	0	0
3	15	Walking	↑	↑	0	↓
5	9	Skiing	0	↑		

↑ = significant daily increase, 0 = no daily change prolonged walking and skiing during four days' of marching or two days' of skiing events. The focuswas on the quantification of the amount of possible disadvantage caused by physical activity. The hypothesis of this study was that strenuous prolonged exercise during consecutive days would decrease the functional capacity of the lower extremities, disturb the balance of the autonomic nervous system and the secretion of hormones from adrenal cortex and pituitary-testicular axis. Further, negative changes in mood states were expected to occur in concert with physiological responses.

6.1. Study design - strengths and limitations

The strength of this study is in its uniqueness: no similar multi-disciplinary field study of daily repeated prolonged exercise has been published. Vuori et al. (1979) followed skiers daily, but collected data only after the first and fourth days of skiing, not after the second and third. In the study by Shephard (1991) the daily skiing speed was very low, only 3.5 $km \cdot h^{-1}$, and data were not collected daily. Furthermore, only hormonal responses were followed in these studies.

Applied research, carried out in so-called real-world settings, such as this, tends to address immediate problems, which limits the control over research settings but yields results that are of direct value to practitioners (Thomas and Nelson, 1990, p. 5).

A field trial is not without limitations. The preliminary marching study (1-2I) before conducting the primary marching data (Study 3-4) was carried out to reduce the methodological problems (Thomas and Nelson, 1990, p. 155). Studies 5 and 6 initially included only ten skiers out of 5,692 Finlandia Ski Race participants, and one of these withdrew due to a fall. These results were therefore obtained from a small sample and may not be representative of the population of skiers who participate in long-distance events.

The purpose of this kind of design is to fit the design to settings that are more real world-like while controlling as many of the threats to internal validity as possible. The purpose in reversal design with time series is to determine a baseline measure, evaluate the treatment (e.g. exercise), its return to baseline, evaluate the new treatment, its return to the new baseline, and so on (Thomas and Nelson, 1990, p. 297-319) as follows:

O_1 O_2 T_1 O_3 O_4 T_2 O_5 O_6 (Thomas and Nelson, 1990, p. 313),

where O signifies observation or test (subscripts refer to the order of testing) and T (treatment) signifies applied exercise.

A repeated measures design of this type has many advantages (Cook and Campbell, 1979; Thomas and Nelson, 1990, p. 154-155). First, they provide the experimenter with an opportunity to control for individual differences among subjects, probably the largest source of variation in most studies. Secondly, inter-individual variation differences can be identified and separated from the error term, thereby reducing it and increasing the power of the analysis. Thirdly, they are more economical in that fewer subjects are required, and finally, they allow a phenomenon to be studied across time, which is of particular importance in studies of change. However, a repeated measures design is not without problems (Cook and Campbell, 1979; Thomas and Nelson, 1990, p. 155-156). Carryover (treatments given earlier influence those given later), and practical effects (the dependent variables get better as a result of repeated trials in addition to the treatment; also called the testing effect), fatigue (subject's performance is adversely influenced by fatigue or boredom), and sensitisation (subject's awareness of treatment is heightened because of repeated exposure).

In experimental and quasi-experimental studies internal validity means controlling all variables so that rival hypothesis as explanations for the observed outcomes can be eliminated. External validity means a generalisation of the results (Cambell and Stanley, 1963; Cook and Campbell, 1979; Thomas and Nelson, 1990, p. 297-306).

There are eight variables, which are relevant to internal validity and which might produce effects that confound with the effect of the experimental stimulus if not controlled in the experimental design (Cambell and Stanley, 1963): 1) history, the specific events occurring between the first and second measurement in addition to the experimental variable, 2) maturation, processes within the respondents operating as a function of the passage of time, 3) testing, the effects of taking a test upon the scores of a second testing, 4) instrumentation, in which changes in the calibration of a measuring instrument or changes in the observers or scores used may produce changes in the obtained measurements, 5) statistical regression, operating where groups have been selected on the basis of their extreme scores, 6) biases resulting in differential selection of respondents for the comparison groups, 7) experimental mortality, or differential loss of respondents and 8) selection-maturation interaction, etc., which in certain multi-group quasi-experimental designs might be mistaken for the effect of the experimental variable.

The factors jeopardising external validity are: 1) the reactive or interaction effect of testing, in which a pre-test might increase or decrease the respondent's sensitivity or responsiveness to the experimental variable and thus make the results obtained for a pretested population unrepresentative of the effects of the experimental variable for the unpretested universe from which the experimental responders were selected, 2) the interaction effects of selection biases and the experimental variable, 3) reactive effects of experimental arrangements, which would preclude a generalisation about the effect of the experimental variable upon persons being exposed to it in nonexperimental settings, 4) multiple-treatment interference, which is likely to occur whenever multiple treatments are applied to the same respondents, because the effects of prior treatments are not usually erasable (Cambell and Stanley, 1963; Cook and Campbell, 1979).

If the number of subjects is small, as it especially was during in the preliminary study (1-2), only the analysis of variance (ANOVA) for repeated measures test can be used (Thomas and Nelson, 1990, p. 155). Repeated measures ANOVAs have been thought to require the assumption (termed compound symmetry) that all variables within a group must have equal variances, all correlations among variables must be equal, and covariance matrices of all groups must be equal. These assumptions are seldom met in repeated measures studies, and they have been shown to be unnecessarily strict (Cook and Campbell, 1979; Thomas and Nelson, 1990, p. 155).

In this study the lack of a control group meant that many other factors (e.g., the test environment, substance use, nutritional status, stress level, sleep deprivation, previous activity, age, sex, diseases) apart from the exercise may have had a confounding effect for example on the hormone results. In addition, the data collection and handling procedure (specimen collection, data manipulation, and analysis) may admit confounding factors such as posture, circadian and rhythmical variation, specimen collection and storage, choices of specimens, analytical and biological variation, descriptive statistics and inference (Tremblay et al., 1995). Most of these factors were partly standardised in this design. The fact that no rest trial was used in this study makes it difficult to draw conclusions about the responses to exercise because the circadian rhythm of the hormones, the small variation (± 1 h) in taking the post-exercise blood sample, and the systematic time pattern between the days, could have influenced the results. Anyway, during prolonged physical stress the circadian rhythm of testosterone has been found to extinguish below the minimum and that of cortisol abolish above maximum level of the control experiment (Opstad, 1994). Nevertheless, what was interesting about this study was that it took place during a prolonged real situation that could not have been reproduced in a laboratory.

It is easier to establish reliability of measurement in research than validity (e.g., stability, alternate forms, and internal consistency) (Thomas and Nelson 1990, p. 352). The coefficient of stability was determined by the test-retest method on separate days. The alternate-forms method of establishing reliability involves the construction of two tests, which both supposedly sample the same material. An internal consistency reliability coefficient can be obtained by e.g., the same-day test-retest, the split-half method, the Kuder-Richardson method of rational equivalence, and the coefficient alpha technique (Thomas and Nelson, 1990, p. 353). For instance, the error of testing jumps, when compared with film analysis has been reported to be in the order of ± 2% (Komi and Bosco, 1978) and the reliability coefficients for the repeated measures of flexibility of the lower extremities have been reported to vary from 0.90 to 0.98 (Wang et al., 1993). Also the circumference measurement has been evaluated to be a reproducible method which has been validated (Perrin and Guex, 2000). However, it is not always correlated with leg (including foot) volume measurement (e.g. water displacement method) and it measures the perimeter at a single level (Perrin and Guex, 2000). To diminish the errors, the same technicians performed all the field measurements in this study. Serum hormone concentrations were measured using the commercial radioimmunoassay kits. The gonadotrophins were assayed by immunofluorometry, which is a sensitive method for detecting very low concentrations of gonadotrophins (Jaakkola et al., 1990; Huhtaniemi et al., 1992).

6.2. Physiological responses to daily repeated prolonged exercise

6.2.1. Cardiorespiratory system

Cardiorespiratory loading in studies 1-4 were at the same level as had been measured during a brisk walking speed (4.8-6.4 $km \cdot h^{-1}$) when the heart rate of middle-aged men on a level surface had been estimated to be 40 to 60% of maximal aerobic power and 50 to 70% of maximal heart rate (Vuori, 1982; Rodgers et al., 1995). Energy consumption during the marches in the present study, estimated by average walking speed, body mass of the subjects, and the weight of the boots, was ca. 1,220-1,360 $kJ \cdot h^{-1}$ (290-324 $kcal \cdot h^{-1}$) (McArdle et al., 2000, p.

170), which means a total energy cost of 9.7-11.6 MJ (2,320-2,754 kcal) during 8-8.5 hours of daily activity. Oxygen uptake was approximately 17-20 $ml \cdot kg^{-1} \cdot min^{-1}$ (4.8-5.7 METs) (Holewijn et al., 1992) which was 27% of VO_{2max} and 23% of oxygen uptake reserve ($VO_2R = [(VO_{2exercise}$ - 1 MET)·(VO_{2max} - 1 MET)$^{-1}$] (Howley, 2001). The mean heart rate level was ca. 60% of the maximal heart rate. At this level energy is produced aerobically, especially through the oxidation of fatty acids. The intensity of endurance-type exercise has been defined to be light if the percentage of VO_2R is between 20 to 39, percentage of HR_{max} 50-63, and VO_{2max} 27-44 $ml \cdot kg^{-1} \cdot min^{-1}$ (3.2-5.3 METs) (Howley, 2001). The physiological threshold of 'comfort' represents 70% of the maximum heart rate (Morris and Hardman, 1997). De Wild et al. (1997) studied 97 over 70-year-old men, who completed the 1993 Nijmegen Four-Day long-distance March (30 $km \cdot day^{-1}$ on four consecutive days). The mean velocity was 5 $km \cdot h^{-1}$ and the mean relative exercise intensity was 52% of VO_{2max} and 70% of HR_{max}. VO_{2max} was the most important predictor of the variation in self-selected velocity.

The skiers maintained the same mean heart rate in both days but the mean skiing velocity during the free technique race (second day) was 12% faster (5.0 vs. 4.4 $m \cdot s^{-1}$) than during the classical technique race (first day). The effect of skiing technique (diagonal stride or skating) at similar heart rate on the skiing velocity was consistent with previous studies (Karvonen et al., 1989; Bilodeau et al., 1991), in which the skating technique has been determined to be 11-14% faster than classical skiing. The mean heart rates during skiing indicated quite a high level of overall cardiovascular strain (86-87%). This observation is in agreement with that of other long-distance exercises lasting under 5 hours. The metabolic and cardiac loads caused by a 42 to 90 km ski-hike have varied from 64 to 85% of VO_{2max} (Vuori, 1972) and during a 90-km skiing event the respective heart rate represented 72.8 ± 7% VO_{2max} (Oja et al., 1988). During a 55-km cross-country ski race, heart rate was maintained at 77% of the maximum for a mean duration of 4.4 hours (Kennedy and Bell, 1996), while in cycle races of 105 km and 110 km (2 h 35 min and 2 h 45 min, respectively), the heart rate was reported to be 79% and 82% of the maximum (Palmer et al., 1994). Luurila et al. (1994) reported that the highest mean hourly heart rates during 75 to 90 km race skiing were 150 $beats \cdot min^{-1}$ and the maximum heart rate was 161 $beats \cdot min^{-1}$, which occurred in most skiers (who were in healthy middle-aged men) during the first hour of the race.

During strenuous cycling (Tour de France) 70% of the heart rate has been measured to be under the first ventilatory threshold, 23% between thresholds, and only 7% above the second ventilatory threshold (Lucia et al., 1999). The energy expenditure of the cyclists for a period longer than seven days has been reported to be from a mean of 25.4 $MJ \cdot day^{-1}$ to peak values of 32.7 $MJ \cdot day^{-1}$ (Saris et al., 1989a) and 62% of energy was derived from CHO, 15% from protein, and 23% from fat.

In cross-country skiing, fatigue may be a result from energy depletion (e.g., glycogen, blood glucose), inadequate oxygen delivery (e.g., total haemoglobin mass) or disturbances in homeostatic functions (e.g., fluid balance) (Rusko, 2003a). The study of Oja et al. (1988) suggests a trend of decreasing heart rate over time in long-distance skiing. It was contented to relate to the depletion of glycogen stores and the consequent shift towards fat utilization as the energy source (Oja et al., 1988). This phenomenon would lead to a slower pace, but unfortunately such changes were not followed in this study. Nevertheless, skiing 50 km requires 15 MJ of energy, 99% of which is produced by the aerobic breakdown of fats and carbohydrates (Rusko, 2003b). The share of carbohydrates is 50 to 60% on average, but it can vary. During the first 10 km, carbohydrate breakdown may provide 70 to 80% of the energy needs, but during the final 10 km this figure may be lower than 20 to 30%. During 50 km of skiing, muscle glycogen stores decrease to 10 to 15% of the starting level (Rusko, 2003b). An average weight reduction of 2% after both skiing sessions in this study indicated probably both muscle glycogen depletion and slight dehydration, which was, however, compensated for by the next morning. However, there was no haemoconcentration after the second day of skiing and the haematocrit remained unchanged (Study 5).

In endurance events, especially in mass starts, it is possible to pace up with another participant, which can result e.g. in skiing a 6% reduction in total mechanical power output with speeds of 5.5 $m \cdot s^{-1}$ and no head wind (Street, 1990). The heart rate responses to skiing have been found to be significantly lower (5.6%) when drafting than when leading (Bilodeau et al., 1994) and in mass-start road races in cycling the HR responses have been found to be more a function of tactical bunch riding than of terrain (Palmer et al., 1994). Although the effect of drafting on the heart rate could not be determined in this study, the opportunity to draft during skiing could have influenced the heart rate results. However, a reduction in total mechanical power output caused by drafting cannot induce increased heart rate levels. On the contrary, it could only have resulted in decreased heart rates. Although many mass sporting events like the Finlandia Ski Race emphasise participation rather than performance, the levels of cardiorespiratory strain observed were indeed high and therefore presented an increased risk of serious complications for subjects with overt or latent cardiovascular disease (Vuori et al., 1983). Luurila et al. (1994) found significantly increased arrhythmias in middle-aged men during exhaustive prolonged exercise as compared to those observed during a similar period of time of normal daily life. In 2003, for example, two participants (both middle-aged men) in the Finlandia Ski Race died. In men aged 50 to 59 years the incidence and relative risk of sudden death in cross country skiing has been estimated to be one per 0.7 million sessions or per 31,000 skiers per year (Vuori et al., 1983). Vuori (1986) has exemplified eventual precipiting factors analysing the situation some minutes after the start of a ski race. First, most of the participants are older middle-aged men and there are a number of persons who are not completely healthy. Second, the excitement, lack of sleep, smoking or alcohol use before the event. Third, the combination of cold weather, full speed and an unprovided warm-up. Fourth, stumbles, collisions, the competitive spirit and dehydration. Surely, all these elements were present during the Finlandia Ski Race, but the starts have been limited nowadays to groups of 500 skiers at one time so that the rush and jam are reduced. The skiers are staggered into the start groups according to their previous year's results.

Thomas et al. (1995) have studied the physiological and perceived exertion responses to six modes of submaximal exercise. On the 14-RPE trial, oxygen consumption and oxygen pulse were significantly higher during jogging than during other exercise modes. Ratings of perceived exertion were significantly higher during cycling than during jogging. These results indicated that different exercise modes have different cardiorespiratory responses.

Oja et al. (1988) recorded heart rate during mass events of 132-km cycling, 35-km rowing, 33-km running, and 90-km cross-country skiing over one year. The mean event time of the subjects was 4 h 58 min for cycling, 4 h 20 min for rowing, 3 h 30 min for running, and 8 h 29 min for skiing. The respective mean heart rates represented 79.3, 72.9, 85.7, and 72.8% VO_{2max}. The proportion of event heart rates above the level representing the 90% event-specific maximal heart rate was 31.2% in cycling, 17.9% for rowing, 59.7% for running, and 21.6% for skiing. A statistical comparison of the mean event heart rates indicated that the heart rate was lower in rowing than in jogging and cycling and also lower in skiing than in jogging. Their results showed that the cardiorespiratory strain of middle-aged nonathletic men during long-distance mass events of cycling, jogging, and skiing is high and relatively comparable to that of well-conditioned athletes.

6.2.2. Autonomic nervous system

In this study the significant elevations were observed in the morning heart rate test after four days marching but not after two days skiing. Dressendorfer et al. (1991) found no changes in heart rate at rest after seven days of increased training. During a 20-day Great Hawaiian Footrace the averaged morning heart rate decreased during the first eight days and then progressively increased, with significant elevations on days 17 and 20 compared to day eight (Dressendorfer et al. 1985).

At rest, the heart rate setting depends on complex neurohumoural interactions (Dressendorfer et al., 1985). Dressendorfer et al. (2000) suggests that a valid marker of insufficient physiological recovery during excessive training is the elevated morning heart rate that is persistently more than 10% above the normal baseline, as occurred in this study. During six days of a moderate prolonged exercise period heart rates increased by about 10% in the night, compared to the previous control condition (Roussel and Buguet, 1982). It was apparently not related to changes in body temperature, haematocrite, sleep patterns, cortical adrenal or thyroid functions. The most likely explanation for the nocturnal tachycardia was related to the increased sympathoadrenal activity (Roussel and Buguet, 1982).

6.2.3. Musculoskeletal system

During physical activity musculoskeletal problems arise from external (equipment, shoes and surface) and internal (anthropometric facts and individual situation) variables as well as movement characteristics (frequency), which influence the load and may be connected to pain and injury (Nigg et al., 1984). Further, the intensity and the amount of exercise are important factors affecting the loading.

In 1993 and 1994, 35,101 and 33,834 walkers started Four-Day March in Nijmegen, and 2,747 and 2,858 (7.83 and 8.45%) did not finish it. The overall dropout rate in 1993 for first time participants was 15.4% (Program-Magazine De 4 Daagse, 1994). In Finlandia Ski Race (1995) 3% of 3,850 participants did not finish the first day's race. During the second day 6% did not finished the race (Finlandiahiihto, 2004), which is more than in Vuori's (1972) study. None of the subjects in the present study perceived musculoskeletal or other health problems serious enough to discontinue marching or skiing, or to necessitate medical attention during or immediately after the event, except one individual who fell during the second day of skiing and dislocated a finger. According the organizer's statistics (unpublished data) there were 68 contacts to the first aid during 2002 Finlandia Ski Race representing 1.6% of the participants. Abrasions (n=26) and muscle cramps (n=15) were the greatest reasons.

In studies 1 and 3, the level of perceived pain (VAS-scale) was already significantly higher after the first marching day, and more pronounced after the last two marches. A similar time profile was also separately found for lower limb pains, which focused on musculature, joints and feet. Unfortunately the pain data was collected only on the first and seventh/ninth day after the exercise, and not for example 48 h after the last exercise. It is known that delayed onset muscle soreness is greatest 1 to 2 days after the exercise (e.g., Clarkson and Tremblay, 1988; Enoka, 1994, p. 277), and with this protocol of the physiological measurements that information was insufficiently received.

In a six-day track race the majority of musculoskeletal injuries presented on the second day (Bishop and Fallon, 1999). Joggers, whose daily running session lasted two hours, had persistent leg muscle soreness after the third day (Dressendorfer et al., 1991). The rest of the perceived pain in studies 1 and 3 were mainly due to abrasions on the shoulders caused by the straps of the backpacks. When these two studies (1 vs. 3) are compared, slightly more acute muscle pains were reported in study 3. This could be explained by subjects' lower training background (6.0 vs. 9.3 $h \cdot week^{-1}$) and higher body mass (79.4 vs. 74.4 kg). The proportion of subjects suffering from leg muscle pain remained approximately the same (50%) but the mean scoring of pain increased (score ranges "slight pain - painful") until the end of the last march. Unfortunately pain scoring and location data were collected using only a structured questionnaire. Therefore the pain cannot be exactly located to specific muscles as only muscle groups were indicated. The majority (ca. 65%) of muscle soreness was experienced in the anterior and posterior thigh muscle groups (quadriceps femoris and hamstrings) with the rest (ca. 35%) located in the calf and gluteus muscles.

Anti-inflammatory analgesic drugs (acetylsalicylic acid, ibuprofen, ketoprofen, indomethacin, naproxen) were used by four subjects in study 1 during all marching days and in addition by one subject during the last day. The average daily number of tablets (Burana® 400 mg, Ketorin® 50 mg) consumed per subject was 2, 3, 3, and 4 during the effort. In study 3 no one used anti-inflammatory analgesic drugs during the first day. During the second day there were three subjects and during the last two days seven who used the drugs. The average daily number of tablets (Aspirin® 500 mg, Burana® 400-600 mg, Ketorin® 50 mg, Ibusal® 200-400 mg, Orudis® 100 mg) consumed during the last three days was 2, 3, and 3 in study 2. Beer was used by some of the subjects after finishing the daily marches (half to one litre per subject). In study V the use of analgesic drugs or beer was not recorded.

Blisters and abrasions on the feet were some of the major problems usually encountered during walking. For example, during the Exercise Fastball in France, where soldiers marched 204 km in six days, all of the injuries were due to foot disorders, such as blisters (Myles et al., 1979). The factor limiting performance for many of the subjects who marched on the hard road surface has been the condition of their feet (Myles et al., 1979). The pain located in the hip, knee and ankle area might be of such types as tendonitis, periostitis, or hydropsis, which are very common medical problems during marching (Hedman, 1988; Rudzki, 1997b). Feet pain originating from friction blisters and abrasions were experienced by almost every subject in studies 1 and 3. The locations of the abrasions were those areas, which were evidently most exposed to pressure and strong friction. The most important factors for producing abrasions were the constant repetitive pressure on the sole of the foot during walking as well as the frictional forces exerted between the skin, socks and shoe soles. These shearing forces generate mechanical fatigue in epidermal cells, leading most probably to the loss of cell-to-cell integrity hence the development of blisters. Tobacco use, ethnicity, foot type (pes planus), a sickness in the last 12 months and no previous active duty military service experience are blister risk factors in cadet basic training (Knapik et al., 1999) but e.g., abnormalities of the foot were not significant factors in the development of injury during recruit training (Rudzki, 1997c). The subjects in studies 1 and 3 wore similar boots (weight 1,400 g) and cushioned them individually. Hard surfaces (asphalt and stone covered roads) provide soft, cushion-soled footwear the ability to allow mobility of the foot and ankle, as well as to dampen the thight, prominent impact forces. On hard ground a boot is inferior to running shoes in preventing problems due to walking or running (Cavanagh, 1980; Jones, 1983). In addition, the temperature inside black boots will rise to very high levels while marching in sunshine and this effect, especially when combined with limited perspiration, is probably an additional factor responsible for abrasions, especially at high speeds (Hedman, 1988). For example, Hedman (1988) has studied the treatment of foot abrasions during a 160-km march (four days), and he conjectured that about 50% of the treated cases (n=39) would probably have been forced to stop the march if they had not had access to hydrocolloid treatment. Of the 527 soldiers, 150 (28%) consulted a doctor in the course of the Four-Day March in Nijmegen in 1996 (Hysing and Fretland, 1997).

Discomfort in the hip and shoulder areas could be reduced by adding more padding to the pack harness surrounding the areas of the iliac crest and shoulders. The pelvis rotates in the frontal plane opposite to the shoulder girdle during most of the stride cycle. When walking at a speed of 6.5 $km \cdot h^{-1}$, each foot will be lifted about 30 cm, and accelerated to twice the average velocity of the body, and then decelerated to zero velocity again (Holewijn, 1990; Holewijn et al., 1992). When this movement is impeded due to the 10.4-kg load supported by the shoulder, the trapezius muscle has to generate a 17 N extra absolute force level (above walking with no load) per shoulder in order to overcome this (Holewijn, 1990). Lightening and reconfiguring the load to move it closer to the body and improving load distribution have been recommended in an attempt to alleviate symptoms associated with carrying heavy loads (Johnson and Knapik, 1995).

In contrast to a previous study of strenuous road marching (Knapik et al., 1997), low back problems were not a major issue in studies 1 and 3. The reason for this difference may be the lightweight load carried and the non-maximum walking speed. When biomechanical and metabolic effects of varying backpack loading on simulated marching was studied (Quesada et al., 2000) notable declines were observed for knee extension moment peaks suggesting that the knee may be effecting substantial compensations during backpack loaded marching. On the contrary, kinetic data indicated that such knee mechanics were not sustained, and suggested that excessive knee extensor fatigue may occur during prolonged loaded walking (Quesada et al., 2000).

An optimum method of load carrying should induce stability, bring the center of gravity of the load as close as possible to that of the body and rely on the use of large mass muscles (Legg, 1985). The concept of distributing the load mass more evenly around the center mass of the body has both positive and negative aspects (Knapik et al., 1997). Feet and shoulder problems could most probably be completely eradicated by means of considerations and technical solutions. The musculoskeletal loading during prolonged exercise could be adjusted by changing the gait and carrying technique. For example, Bishop and Fallon (1999) argued that there might be another reason beside the onset of blisters for the gait changes. This second possible factor is “favouring” injuries, which are present already at the start of the race or those that develop during the race, and lead to gait changes and increased stresses elsewhere.

Military basic recruit training is known to be associated with an increased risk of overuse injuries (e.g., Ross, 1993a; 1993b; Jordaan and Schwellnus, 1994). The overall incidence of injuries in military recruits undergoing basic training was 1.8/1000 training hours (Jordaan and Schwellnus, 1994), but a much higher rate of injuries (13-15/1000 h) was found in Rudzki’s (1997a) study where field training was not included. Overall, most injuries treated in US Army outpatient clinics were lower extremity training-related injuries (Jones and Knapik, 1999). The highest incidence of injuries was recorded in weeks one to three and week nine of training, which were weeks characterised by marching (> 77% of the training time). The amount of overuse injuries may be diminished, if the possible overpronation is diagnosed with orthoses (Lehti and Rehunen, 1992), and training is modified (Jordaan and Schwellnus, 1994). The lower marching volume did not lessen morbidity (Giladi, et al., 1985).

In cross-country skiing the most common overuse injuries to the upper extremities are tendonitis/tendinosis of the rotator cuff and of the distal triceps or brachii of the proximal biceps, impingement syndrome or subacromial bursitis, and epicondylitis (Ronsen, 2003). In lower extremities the most common overuse injuries in cross-country skiers are inflammation of the hip adductors, external rotators or flexors, tibialis anterior, plantar fascia and Achilles’ or flexor hallucis tendon, minor tears or spasms in the hip or leg muscles, iliotibial band friction syndrome, patellofemoral pain syndrome, and medial tibial stress syndrome/shin splint (Ronsen, 2003). The most common injuries to the trunk/spine are inflammation of muscles, tendons, ligaments and joints, spondylolysis and spondylolisthesis, lumbar disc degeneration, protrusion and herniation, and scoliosis or Scheuermann’s disease in the thoracic spine (Ronsen, 2003). In cross-country skiing, fatigue may also be of neuromuscular origin (decreased central recruitment and peripheral force production) (Rusko, 2003a).

No significant changes in the functional capacity of the lower limbs (vertical jumps, range of motion, circumferences) were observed in the present study. The high volume of walking was assumed to decrease the functional capacity of the lower extremities, because for example, even a single marathon run has caused an acute loss of muscle function (Sherman et al., 1984; Nicol et al., 1991a; 1991b; Kyröläinen et al., 2000). Hence, the discrepancies between our results and those seen after marathon running are evidently caused by the extremely heavy and competitive nature of those events. Walking compared to running causes 3.6-fold lower ground reaction forces (Voloshin, 1988). Thus, similar to the present results, no significant changes in the leg muscle fitness test results (e. g., vertical jump test) have been found after 20-days of running (Dressendorfer and Wade, 1991). Limitations of the range of motion of any lower extremity joints will disrupt gait mechanics and have been found to be associated with an increased risk of ulceration (Sumpio, 2000).

In the present study, a relatively moderate increase (400 to 825%) was observed in serum CK throughout the marching periods. An increase of this magnitude can well be caused by facilitated protein transfer via the lymphatics from muscle interstitium, and not necessarily from the myocellular compartment into intravasal compartments (Komulainen et al., 1995). Therefore, great care must be taken when interpreting such small changes in serum CK as in this study (max. increase 9.2-fold) and e.g., in the study done by Ross et al. (1983; seven fold increase), to mean serious pathophysiological phenomena in a muscle, in contrast to, for instance, changes after eccentric bench-stepping exercise, when CK increases may be 350-fold (Newham et al., 1983).

In study 5, CK activity increased only about 3 times from the initial value. This is in accordance with an earlier 90 km skiing study (Refsum et al., 1972).

6.2.4. Endocrine system

Urinary catecholamines were assayed in order to quantitatively estimate sympathoadrenal stress. Both adrenaline and noradrenaline excretion rates showed cumulative sympathoadrenal stress during marching period, seen not only as cumulatively increasing excretion during the successive marches, but also, interestingly, as a tendency for cumulatively increasing night excretion. Due to a lack of reference data, the evaluation of the usefulness, especially during night excretion, of catecholamines as an estimate of general sympathoadrenal stress remains open. A similar type of cumulative sympathoadrenal loading response was found in the skiing study of Vuori et al. (1979) where the basal noradrenaline plasma levels were increased during the first days of a ski-hike. In four days, they reached a plateau.

The only acute increasing response of the adrenal cortex to marching was measured after the first exercise session in study 3, despite the peak value accruing in the morning (Marniemi et al., 1984). Either overall hormonal stress adaptation occurs in about a day for the present type of prolonged walking or fatigue induced by the prior exercise may have modified the hormone response by provoking a feedback suppression as demonstrated by Brandenberger et al. (1984). The suppressed response reported here was more rapid than that seen in earlier studies (for example, Marniemi et al., 1984; Fellmann et al., 1992) in which stabilisation occurred over three days. During the last three days both pre- and post-concentrations of serum cortisol levels gradually decreased towards normal resting values. Serum cortisol was no longer elevated after the last walk or on the following morning after, when compared with the baseline samples taken before the first march. A significantly elevated cortisol level was still detected after nine days of recovery, but this could have been due to the circadian rhythm of cortisol secretion since the recovery sample was taken earlier than the Post samples following the marches (1:00 to 2:00 vs. 2:30 to 6:30 p.m.).

It is generally accepted that during prolonged severe exercise the secretion of cortisol and therefore blood levels as well are progressively increased (Marniemi et al., 1984). Lowered or suppressed cortisol responses to subsequent exercise have been speculated to represent a maladaptation or pathology in the athletes (Lehmann et al., 1998; Hackney and Styers, 1999). Viru et al. (2001) found two different types of resetting of the regulation of pituitary-adrenocortical activity to subsequent exercise after prolonged (2 h) continuous running: one involved an intensified mobilisation of pituitary-adrenocortical function while the other reflected the inhibition of activity within this system produced by the fatigue.

After the first and second days of walking, the concentration of serum testosterone decreased when compared with the pre-march baseline, but not after the third and fourth days. There was also a significant decrease after the second day compared with the morning level. Hence, secretion of testosterone appears to adapt to repeated prolonged (8 to 11 h) low intensity (57 to 61%) walking within three days. Although the concentrations of anabolic hormones (testosterone, LH, FSH) before the event were within the reference limits i.e., they were quite low. Therefore it is presumable that changes in initially lower hormone concentrations will be smaller than in higher levels. Endurance trained men, such as the subjects of the present studies, who had trained for six to nine hours per week, have been reported to have a lower basal serum testosterone concentration than control subjects (Wheeler et al., 1984; Hackney et al., 1990; Gulledge and Hackney, 1996).

LH tended to increase during the first day and significant decreases were seen after the second and the third day when compared to the pre-march baseline. The decrease was also seen after the third day compared to the morning level, but there were no changes during the fourth day. Hence, the acute response at the pituitary level of the hypothalamic-pituitary-testicular axis (excluding secretion of FSH) also seem to disappear within four days. No acute march response on FSH was seen during the first day, but thereafter FSH declined during the last three days and the pre-march concentration of FSH did not rise significantly between the end of the third and the beginning of the last exercise session. Thus, no adaptation to repeated low intensity prolonged walking was seen in FSH. The difference in these results compared with studies that have detected no decrease in gonadotropins after prolonged exercise (Dessypris et al., 1976; Schürmeyer et al., 1984; Lucia et al., 2001) may partly be explained by the improved precision and accuracy of the analytical method (IFMA) used in this study (Jaakkola et al., 1990; Huhtaniemi et al., 1992).

Earlier studies have reported a higher concentration of serum FSH in trained subjects, which is considered to be a sign of compensating hypogonadism due to several years of physical training or dysfunction of the Sertoli cells (Vasankari et al., 1993). These conclusions are in accordance with the present results. The secretion of FSH is unlikely to adapt to repeated prolonged exercise.

The results of the body mass and haematocrit in study 6 was similar to marathon runners during a 20-day road race (Dressendorfer et al., 1981). An average body mass reduction after each walking session (1 to 2%) indicated slight dehydration, which was, however, compensated for by the next morning. However, possible haemoconcentration caused by dehydration could not induce the reduction of postexercise serum concentration of testosterone, LH or FSH. On the contrary, possible haemoconcentration could result instead in increased concentrations. Sleep deprivation or a low-energy diet, which could have a major influence on the hormonal results, were not included in this study, and all subjects were healthy adult men. The hormonal comparisons were made with the baseline samples (PreI samples and 0 p.m. samples), which make the interpretation of the change possible.

6.3. Mood states after daily repeated prolonged exercises

Although significant increases in mood disturbance within a period of 3 to 4 days following the onset of increased loading may be provoked (Morgan et al., 1988), no significant changes in mood states were found in this study. After the daily marches the soldiers felt tired, listless and sluggish but not totally exhausted or fatigued. The mood factors (Fatigue-Inertia and Vigor-Activity), which contain an obvious somatic component, are found to display the greatest alterations (Raglin et al., 1991). The increase in the Fatigue-Inertia and the decrease in the Vigor-Activity affective state during the 4-day march represented a mood of weariness, inertia and low energy level. The increase in the Tension-Anxiety affective state represented a heightened musculoskeletal tension. It included the reports of somatic tension, which may not be overtly observable (tense, on edge), as well as observable psychomotor manifestations (shaky, restless). Overall, the present results indicate that the participants could cope with the psychological stress and repeated monotony of prolonged exercise over 4 days without notable mood changes.

Also after two days of skiing the subjects felt tired, listless and sluggish but not exhausted or fatigued. The increase in the Fatigue-Inertia affective state represented a mood of weariness, inertia and a low energy level.

Usually improvements in mental health are associated with aerobic exercise, but the results of a study by Hale et al. (2002) indicate that combined sessions of aerobic and resistance exercise reduced anxiety, and that the order in which the exercise is preformed does not influence this response. The same kinds of results have been found in acute resistance training (Hale and Raglin, 2002). Anxiety has been found to decrease following different intensities (40-70% VO_{2peak}). However, this reduction was delayed somewhat following exercise at a high intensity (Raglin and Wilson, 1996). When O'Connor et al. (1991) studied the effects of 3 days of increased training in swimmers; significant reductions in vigor were observed as a consequence of the greater training load.

6.4. Recommendations for future research

Exercise stress elicits varied responses in different subjects, and frequently identical exercise stress will elicit varied responses in the same person at different times. This is called individual specificity of exercise (Edington and Edgerton, 1976, p. 4). Therefore the results of field studies are situational and the background of the subjects and exertions must be well described. Different exercises have different biological requirements. Exercises could be classified according to the speed of movement, resistance to the movement, and duration or the time over which the movement has to be repeated. These three classification components are simultaneous and additional variables affecting the activity or environmental factors must be taken into consideration. Mental and social pressures and dietary considerations must be added to the total consideration for exercise classifications (Edington and Edgerton, 1976, p. 4-7).

In this study the types of exercises were walking and skiing, but many other endurance exercise types could also be very prolonged, for example cycling, golf, orienteering, paddling, rowing, running, skating, and swimming, and provide fields of investigating. The physiological responses of these long lasting aerobic exercises should also be studied within the normal population (both men and women, young vs. older people) and not only in regularly training and competing athletes because the responses could be different. It would be important to find the limit beyond which signs of over-dosage may develop. This may be the reason why many discontinue their training programs, which they have started with great hopes. The critical borderline to physiological overload during daily repeated exercise still remains open and further investigations are needed.

The present findings can be generalised partly to the army and other physically strenuous occupations. In the soldier's action competence model (Toiskallio, 1998) four elements can be distinguished, i.e. 1) physical fitness/performance, 2) psychological, 3) social, and 4) ethical competence. A soldier in action forms part of the situation and the environment where he acts. The soldier's action is contextual.

Mental strength is an important ability, and can be seen as stamina, determination, bravery and the will to win (Defence Staff, Finnish Defence Forces, Department of Education 1999). From the holistic perspective, the same elements could also be seen in sports. When functional capacity and working ability or the athlete's training state are under evaluation or research in the field environment, components other than physical fitness/performance are worth remembering and researching.

7. CONCLUSIONS

The main findings and conclusions of the present series of studies on fit male volunteers can be summarised as follows:

1) The cardiorespiratory response to daily repeated walking over 8 hours was moderate (60% of maximum heart rate) and to daily repeated 3 hours skiing it was strenuous (90%).

2) The increased orthostatic heart rates were found after four days of very long, and moderate walk, but not after the shorter but more strenuous ski race.

3) Muscle pain was perceived during and after the two different exercise series, but neither very long, moderate walking nor long, strenuous skiing induced any changes in the functional capacity of the lower extremities.

4) Catecholamine excretion rates during marching indicated cumulatively increased sympathoadrenal stress. A daily repeated prolonged, moderate walk and a strenuous, long lasting ski event evoked the hormonal secretion of the adrenal cortex (cortisol) and pituitary-gonadal axis (testosterone, LH, FSH), but the response disappeared within four days of repeated prolonged exercise (excluding the secretion of FSH after maching) and no dramatic long lasting changes occurred.

5) Fatigue was perceived after the two different exercise series, but total mood state was stable.

6) Incorporation of multidisciplinary research allows for the collection of holistic information during field studies where physical as well as psychosocial competencies are present.

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9. AUTHOR BIOGRAPHY

Ilkka VÄÄNÄNEN
Employment
Researcher,Lahti Polytechnic Faculty of Social and Health Care, Finland
Degree
PhD
Research interest
Exercise physiology
Email:
ilkka.vaananen@lamk.fi

✉ **Dr. Ilkka Väänänen**
Lahti Polytechnic, Faculty of Social and Health Care Hoitajankatu 3, FIN-15850 Lahti, FINLAND