Chapter 7 – INTRINSIC AND EXTRINSIC FACTORS AFFECTING OPERATIONAL PHYSICAL PERFORMANCE

Section 7.1 – INTRODUCTION

The preceding chapters in this report have addressed the performance of common military tasks. Performance has been dealt with in terms of physiological and fitness requirements and methods of training to achieve performance goals. This chapter will deal with factors outside the training realm that influence performance on these military tasks. These factors are either individual (intrinsic) or environmental (extrinsic) characteristics. In general, effects of these factors cannot be overcome completely by additional physical conditioning.

The intrinsic factors considered are age, gender, body dimensions, and genetics. The extrinsic factors that will be considered are effects of nutrition (including hydration), heat, cold, altitude, clothing, and extended operations. The sections in this chapter are intended to increase reader awareness that performance is not determined simply by training and execution. They are meant to be introductions rather than exhaustive coverage of fundamental concepts in each of the areas presented. The contributors hope you will find these presentations helpful and informative.

Section 7.2 – EFFECTS OF AGE ON OPERATIONAL PHYSICAL PERFORMANCE

by

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ABSTRACT

Age is widely regarded as the most important determinant of the loss of an individual's physical performance capability over time. Said loss is of concern for employers of personnel involved in physically demanding occupations, particularly military personnel. A minimum level of physical performance is a prerequisite for military personnel because the absolute physical job demands are often dictated by extrinsic factors that cannot be altered. A reduced work capacity may lead to inadequate performance, increase the risk of overuse injury, and, ultimately, compromise effectiveness of military operations. However, appropriate training can counter the effects of aging on strength and endurance and enable the individual to maintain adequate levels of performance late into life.

7.2.1 BACKGROUND

Increasing age leads to inadvertent changes in maximal performance capacity (Samson et al., 2000; Booth et al., 1994; Bemben, 2003). Physiological functional capacity (PFC), the ability to perform the tasks of daily life in an effortless and successful manner (Donato et al., 2003) also decreases. Muscular strength and endurance are the most relevant of all physiological measures limiting physical performance (Frontera et al., 2000; Fitzgerald et al., 1997; Janssen et al., 2005). Deficits in strength and endurance have a negative impact on performance in common tasks like locomotion, or lifting, handling, or carrying loads (Bemben, 2003; Leyk et al., 2006a; Leyk et al., 2006b). With the changing demographic structures in western societies, this will become a major concern not only in everyday life, but especially in physically demanding occupations like the automotive and shipping industries or the military services where exogenous factors often cannot be altered, thus dictating the physical demands of occupations.

7.2.2 AGE-RELATED CHANGES IN MUSCULAR STRENGTH

The human musculoskeletal system produces the strength and power to move and interact with the physical world. Its capacity determines the performance in primarily load-related tasks. For example, handgrip

strength can play a crucial role in load-bearing or transportation tasks such as stretcher carriage (Bilzon et al., 2002; Leyk et al., 2006a; Leyk et al., 2006b). Various studies have described a peak in muscular strength and muscle mass around the age of 20 – 30 years (Janssen et al., 2000; Brooks et al., 1994; Booth et al., 1994; Reeves et al., 2006). A 10 – 15% loss of whole body muscle mass can be observed from age 20 to 80 years, with a concomitant increase in relative and absolute body fat (Janssen et al., 2000). Also, a two-staged decrease in muscular performance can be observed from age 30, with a moderate decline in muscular parameters up to age 55 – 65 years and an accelerated reduction thereafter (Booth et al., 1994). Extents as well as rates of decline appear to be dependent on individual factors, such as genetics, lifestyle, and habitual physical activity (Wilmore et al., 2004; Roubenoff et al., 2000).

Age-related changes occur in:

- Muscle mass;
- Muscle cross-sectional area (MCSA);
- Muscle fiber type composition;
- Reduced number of capillaries;
- Changes in enervation and neural drive;
- Myofibril protein content; and
- Muscle force production and power output.

The most noticeable and critical effect of the aging process is the loss of muscle mass, termed sarcopenia. Sarcopenia occurs around age 55 (Roubenoff, 2003; Booth et al., 1994), and is evidenced by a reduction in MCSA. This reduction is a function of cellular, nutritional, and hormonal changes (Brooks, 2003; Reeves et al., 2006; McArdle et al., 2001; Booth et al., 1994). Reduction in contractile tissue, thickening of Type I fibers, clustering of muscle fibers, and changes in muscle fiber composition concomitant to the reduction in MCSA are also observed (Brooks et al., 1994; Brooks, 2003; Reeves et al., 2006; Roos et al., 1999; Lexell et al., 1986). The loss of MCSA, combined with an increase of non-contractile tissue, results in lowered capacity for force production and, consequently, power output (Maharam et al., 1999; Doherty et al., 1993; Brooks, 2003; Reeves et al., 2006; Lanza et al., 2003). However, force production capability of the contractile tissue itself appears to be largely unaffected by aging (Maharam et al., 1999).

A promising hypothesis for the mechanisms underlying sarcopenia has been formulated. Sarcopenia can be explained as the combined effects of progressive neuromotor deterioration and chronic under-loading of the musculoskeletal system on the single motor unit level (Brooks et al., 1994; McArdle et al., 2001). Lack of use and suspected morphological aspects specific to Type II motor units, together with deterioration in motor unit remodeling capabilities, appear to cause the preferred denervation of Type II fibers (Brooks et al., 1994). The results are muscle fiber atrophy and ultimately the irreversible degeneration of end plate structures and muscle fibers (McArdle et al., 2001). However, denervated Type II fibers may be re-innervated by adjacent Type I motor units by the sprouting of motor nerves and end plates. This hypothesis can account for the observed loss of muscle mass, the change in muscle fiber composition, and the increase in non-contractile tissue. Sprouting of motor nerves to re-innervate previously denervated muscle fibers may provide an explanation for the increase in size of slow motor units as well as for the clustering of fiber types that was observed in both animals and humans with increasing age (Brooks et al., 1994).

7.2.3 AGE-RELATED CHANGES IN ENDURANCE

The relocation of units to remote areas where supplies and equipment must be carried over prolonged periods of time is not solely dependant on strength capabilities. Endurance plays a crucial role in sustained

performance. Endurance capacity is typically predicted in a technical approach by determining the maximal rate of oxygen consumption (VO_2max) from respiratory gas exchange. Available data from numerous cross-sectional and a few longitudinal studies predict various rates of decline from approximately 5% to 20% per decade, beginning at the age of 25 years. Differences in rates as well as in timing and extent are probably due to differences in occupational or leisure time physical activity, lifestyle, genetic profile, disease, and other factors (Leyk et al., 2006c; Dehn et al., 1972; Maharam et al., 1999). However, even though VO_2max is the most frequently used criterion to evaluate endurance capacity, it is only one of the determinants for successful endurance performance. For example, it is not uncommon to see master athletes with lower VO_2max performing as good as, or even better than younger individuals with higher VO_2max values (Allen et al., 1985; Daniels, 1985; Sjödin et al., 1985; Sleivert et al., 1996). Thus, the age-related decline in VO_2max may not inevitably mirror changes in endurance performance.

Running times of endurance events such as marathon or half-marathon races provide an excellent opportunity to study age-associated changes in endurance performance. Leyk et al., (2006a) examined more than 400,000 results from marathon and half-marathon events and found endurance performance, as assessed by running times, remained virtually unchanged within an age group from 20 to 49 years with only minor decreases thereafter. The authors concluded that lifestyle factors have a considerably stronger influence on endurance capacity than age per se.

7.2.4 PREVENTIVE MEASURES TO COUNTER AGE-RELATED CHANGES

Both endurance and muscular capabilities deteriorate with age. This results in a decline in both maximal attainable performances as well as in decrements in PFC. However, it is often difficult to determine whether the observed reduction is a result of biological aging, or of lifestyle, physical inactivity, genetics, or disuse (Rittweger et al., 2004). Age-related changes recorded in physiological measures of highly trained, competitive master athletes can be regarded as a performance “ceiling”, reflecting mainly the results of primary aging with negligible additional margins for improvement through training (Leyk et al., 2006c; Fitzgerald et al., 1997; Rittweger et al., 2004). While the strictly age-elicited changes in maximal performance capabilities seem to be inevitable, physical exercise may still slow, delay, or reverse decrements in PFC. Physically active elderly individuals, such as master athletes, show a slower decline in VO_2max over time compared with their inactive peers, and it has been shown that adequate strength levels can also be maintained (Tanaka et al., 2003; Trappe et al., 1996; Wiswell et al., 2000; Krivickas et al., 2006).

Numerous studies have found that both the cardiovascular and the musculoskeletal system show remarkable plasticity late into life (Pollock et al., 1997; Wiswell et al., 2000; Reeves et al., 2006). As a result, the effects of age on PFC may be slowed, halted, or even be reversed. As seen in Leyk et al’s. (2006a) study, physically active elderly are able to maintain levels of performance equal to those of 20-year-old peers. This implies that endurance training can counter the age-related decrements in endurance that can be observed in less-active peers. Strength training also yields similar results as shown by (Pearson et al., 2002). While maximal lifting performance decreased with age, athletes consistently showed results that were significantly better than those of their age-matched controls. Isometric strength of 80- to 89-year-old weightlifters was higher than that of the less-active control group (ages 40 – 49 years).

The capacity for performance improvements for untrained subjects remains almost constant with increasing age. A roughly 10 to 20% increase in relative performance after a 3-month training regimen can be derived for both strength (Baum et al., 2003) and endurance training as measured in VO_2max from age 20 to 80 years (Hagberg et al., 1989; Meredith et al., 1989). Given the development of age structures in the western world, and the related impending impact on personnel in the workplace, who will have to work until an older age, physical exercise and activity may be the key to maintaining appropriate levels of fitness required both for work and everyday life. Appropriate strength- and endurance training at any age

is the easiest and most effective way to counter the effects of age-related loss of performance (Mazzeo et al., 1998).

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Section 7.3 – EFFECTS OF GENDER ON OPERATIONAL PHYSICAL PERFORMANCE

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ABSTRACT

The most important gender-associated factors regarding physical performance are the well-known gender differences in weight, height, and body composition.

The impact of gender on physical performance, especially for military demands, must be differentiated in muscular strength and endurance capacity. Scientific literature strategies to minimize the gender-related differences are usually of minor practical or military relevance.

7.3.1 BACKGROUND

With the onset of adolescence, gender-specific hormone secretion leads to differences in body size and composition. In women, estrogen secretion increases fat deposition by stimulating lipoprotein lipase activity, especially in the thighs and hips. Furthermore, estrogen secretion increases the growth rate of bone for 2 to 4 years after the onset of puberty. In general, estrogen leads to an increase in fat mass and to a rapid but shorter period of growth and, consequently, smaller body height. In contrast to women, at the onset of maturation male subjects are affected by increasing testosterone levels, leading to increases in bone formation and muscle mass, primarily evoked by testosterone-stimulated protein synthesis. After maturation, men generally have a greater muscle mass and a smaller percentage of body fat.

The most common gender differences regarding physical performance are weight, height, and body composition. Male subjects are generally taller, heavier, and leaner (higher fat-free body mass) than their female colleagues. Of the multiple physiological differences between men and women, body composition is the most important factor affecting physical performance.

7.3.2 GENDER DIFFERENCES IN PHYSICAL PERFORMANCE

Physical performance is a widespread, undefined term. In the military setting at least two characteristics of physical performance generally have to be differentiated and analyzed regarding their diverse capabilities for men and women:

1) Physical performances that require muscular strength, and
2) Physical performances that require endurance capacity.

7.3.2.1 Muscular Strength

The impact of gender on muscular strength is most obvious in body composition. Strength variations between men and women are mainly related to the smaller amount of absolute muscle mass (about 60% of

men) and a higher body fat percentage in women (Janssen et al., 2000). Besides genetic effects this might be caused by a weaker affinity to strength-demanding tasks in women. It must be taken into account that women are 40 to 60% weaker in the upper body and about 25 to 30% in the lower body than men (Shephard, 2000; Kraemer et al., 2001). These regional differences occur due to different muscle mass distributions and different day-to-day activities (Miller et al., 1993; Janssen et al., 2000).

The significance of these regional muscle strength differences is of major concern for several occupational tasks. For rescue, activity, manual load carriage is a very important part of the daily requirements, and handgrip strength is identified as the most crucial variable for this task (Leyk et al., 2006a, b). Recently, (Leyk and co-workers 2006d) investigated some 2000 age-matched young men and women with regard to their maximum handgrip strength. 90% of the female subjects produced maximal handgrip forces smaller than 95% of their male counterparts. Furthermore highly strength trained female elite athletes could not reach the handgrip strength level of the weakest 25th percentile from untrained and not-specifically trained men of the same age (Leyk et al., 2006d).

These physiologically-determined gender differences are disadvantageous for female military personnel who have to perform strength-demanding tasks. The absolute amount of body mass and especially the fat free body mass (FFM) are the predominant factors for physical strength performances. Heavy but lean persons can easily outperform lighter endurance-trained peers on common military tasks like load carriage (Bilzon, 2001; Lyons, 2005).

A common argument that differences in muscle fiber distribution are linked to the considerable strength differences between men and women has not been proven (Drinkwater K, 1984; Wilmore and Costill, 2004). However, the capability of strength development per muscle unit is equal in men and women (Schantz et al., 1983; Shephard, 2000). These findings support the importance of body composition, particularly the absolute amount of FFM, for physical performance that requires muscular strength.

For personnel selection processes, it should be noted that even highly trained female athletes hardly reached the average strength level of unspecific trained males (Leyk et al., 2006d).

7.3.2.2 Endurance Capacity

Endurance capacity can be determined either by the time needed to reach a given distance or in a more technical approach by measuring respiratory gas exchange as well as blood lactate concentrations at submaximal workloads. Most researchers regard the maximal oxygen consumption (VO_2max) as the best predictor of cardio-respiratory endurance capacity.

However, even though VO_2max is the most frequently used criterion to evaluate endurance capacity, it is only one of the determinants for successful endurance performance. For example, it is not uncommon to see master athletes with lower VO_2max who perform endurance competitions as well or even better than younger individuals with higher VO_2max values (Allen et al., 1985; Daniels, 1985; Sjödin and Svedenhag, 1985; Sleivert and Rowlands, 1996). Thus, the age-related VO_2max decline may not inevitably mirror changes in endurance performances.

Running times in endurance events (e.g. marathon, half marathon) provide an excellent opportunity to study age- and gender-associated changes in endurance performance. Leyk et al., (2006c) investigated more than 400,000 running times from marathon and half marathon events and showed that gender and age differences remained constant within an age group of 20- to 49-year-old marathon/half marathon runners. The authors concluded that lifestyle factors have considerably stronger influences on functional capacity than does age or gender. With regard to the gender-associated differences, female finishers required only about 10% more time than their male counterparts, despite VO_2max gender distinctions that are frequently reported to be about 20% (Wilmore and Costill, 2004; Drinkwater, 1983; Shephard, 2000).

The most important gender differences regarding endurance performance are:

- A greater body fat percentage among women means the addition of extra load, which decreases endurance performance.
- Lower blood volumes and hemoglobin levels lead to an increased heart rate at comparable submaximal workloads.
- As a result of their smaller body size, women's hearts are smaller.
- The combination of smaller heart size, blood volume, and hemoglobin level results in a lower absolute and relative ($ml \bullet kg^{-1} \bullet min^{-1}$) maximal oxygen uptake.

These biologically determined circumstances lead to a 10 to 20% gender difference in endurance performance. Weaker results for women are generally seen for running performances or VO_2max adjusted for body weight ($ml \bullet kg^{-1} \bullet min^{-1}$) (Leyk et al., 2006c; Shephard, 2000; Drinkwater, 1984). A further theoretical approach to quantify the sex differences is the expression of VO_2max values per kg FFM. If VO_2max is related to FFM ($ml \bullet kg_{FFM}^{-1} \bullet min^{-1}$) gender differences diminish to about 5 % (Cureton, 1981; Drinkwater, 1984). These differences could be attributed to an inherent biological male/female difference (see above).

However, variations in endurance performances within a gender group seem to be larger than differences between trained men and women. Lifestyle factors and the biological variability are likely to be better predictors for endurance capacity than the gender factor itself.

In contrast to strength-related tasks, highly endurance-trained female athletes are able to easily outperform moderately trained male peers (Drinkwater, 1973). The most popular example for excellent ultra-endurance performance in women is the German female athlete, Astrid Benöhr. Her actual world records in five- and ten-fold "iron man" distance competitions are 2 respectively 5 hours faster than of the fastest male athlete. These results support the scientific findings that women can equally or even out perform men in long-lasting endurance tasks (Bam et al., 1996; Sparling et al., 1998). Hence, for military tasks, which predominantly require endurance capabilities, trained women could reach comparable levels to men.

Independent of gender, subjects with identical body weight and body composition as well as the same endurance training status perform on a comparable level (Pate et al., 1985; Cureton and Sparling 1980).

7.3.3 PREVENTIVE MEASURES TO MINIMIZE NEGATIVE EFFECTS (TRAINABILITY OF MEN AND WOMEN)

Sections 7.3.1 and 7.3.2 showed that major physiological differences between men and women affect their physical performance. Particularly in tasks that require strength, the literature unambiguously reveals a widespread distinction in performances based on gender (Leyk et al., 2006d; Miller et al., 1993; Knapik et al., 1980). Hence, for military personnel selection and personnel assignment, knowledge about the potential margins of improvement in strength and endurance performance through physical training is of particular interest for both men and women.

In general, there are no significant gender specific differences in physiological adaptation processes due to physical training.

- Strength improvements of about 20% in a 10- to 16-week training program are well documented in the literature for both, men and women (Cureton et al., 1988; Kraemer et al., 2001; Staron et al., 1990). Women commonly adapt more easily to strength training processes because of their weaker baseline level. Nonetheless, compared with non-specific-trained men, most women cannot reach a comparable strength level in the upper body musculature (Knapik et al., 1980). However,

strength level in the trunk and lower body area approaches among highly strength-trained female athletes and average-trained men.

- The large variance in muscle strength between men and women is a result of intrinsic, biological factors and the lower affinity for strength-demanding tasks or to resistance training. Nonetheless, as shown by the scientific literature and practical examples in sports, women are not only able to gain strength and power by resistance training, but they even more have to improve their strength level to enhance females readiness in the military setting.
- Improvements in endurance performance as well as physiological adaptation processes (i.e. increases in: stroke volume, VO_2max, peak ventilatory volume, and capillary and metabolic function) are about equal for men and women (Drinkwater, 1984). A 12-week training program yields a mean increase in VO_2max of about 20% (Drinkwater, 1984; Shephard, 2000).

Possible margins of improvement in physical performance depend less on the gender factor than on factors like training status (ceiling effect), training intensity, training volume, proportion of training to recovery periods, or being a responder/non-responder for a given training program. (Bouchard, 2001). Nonetheless, even if relative improvements in both groups (male/female) seem to be equal, the absolute increase, especially in strength-training activities, cannot reach a comparable level.

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Section 7.4 – EFFECTS OF VARIABILITY IN BODY DIMENSIONS ON OPERATIONAL PHYSICAL PERFORMANCE

by

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ABSTRACT

Anthropometry refers to the measurement of living human individuals. Variations are subjected to biological and demographical changes and must be updated continuously by anthropometric surveys. Anthropometric and especially body composition measurements deliver valuable data not only for development of equipment or selection of personnel but also for analysis of physical capabilities.

7.4.1 BACKGROUND

Anthropometry refers to the measurement of living human individuals for understanding human physical variation. These variations are subjected to biological and demographic changes in a given population and can be documented using anthropometric surveys.

For NATO, the methodology for anthropometric data is described in STANAG 2177. These measurements are necessary for the development of military equipment. In addition, at military workplaces anthropometric requirements are often important as selection criteria for appropriate personnel (Friedl, 1992; Hodgdon, 1992). In general anthropometric measurements generate valuable data for ergonomic aspects and give a rough impression of physical performance capability. Certain military workplaces like jet cockpits, tanks need anthropometric pre-selection criteria (e.g. height, sitting height, reaching height, leg length) because the workplace environment is fixed. Apart from these measures of length, characteristics like body weight and body composition (percentage of body fat) are of particular importance to physical performance and other requirements. As stated in Section 7.3, body mass and fat free body mass are important factors modulating physical performance. To assess physical capabilities using anthropometric measurements, body composition is the most important, irreplaceable variable. Therefore, weight-height tables and WHO Body Mass Index (BMI) standards are of minor significance in predicting physical performance. Being overweight (BMI) is not always a problem/issue but being over-fat almost always has a negative effect on physical capability. Without knowledge about the individual body composition, statements regarding physical performance can hardly be derived from anthropometric data.

7.4.2 IMPACT OF BODY WEIGHT AND BODY COMPOSITION ON PHYSICAL PERFORMANCE

As stated above, body composition is, aside from body weight, the most important anthropometric measure for predicting physical performance capabilities. The most accepted techniques for assessing body composition are:

7.4.2.1 Laboratory Techniques

- Hydrostatic weighing involves the subject weighing while he or she is totally immersed in water. After correction for lung volume, body volume can be estimated from the difference between weight measured underwater and that measured on land. Body volume and land weight are used to determine body density, which can be used in 2-compartment models to estimate body fat content as a percent of mass (Wilmore and Costill, 2004; Brodie, 1988 I+II).

- Many other laboratory techniques are available to assess body composition but most of them are quite expensive. These include radiography, computed tomography, magnetic resonance imaging, and isotope dilution technique. (Wilmore and Costill, 2004, 450-456; Brodie, 1988 I+II; Zahariev et al., 2005).

7.4.2.2 Field Techniques

- Body fat content can be estimated from anthropometric variables. The most commonly used variables are skinfold thicknesses measured at various sites with a skinfold caliper, and body circumferences measured with a measuring tape. These anthropometric variables are used in equations to predict either body density or percent body fat (Wilmore and Costill, 2004; Brodie, 1988 I+II). The United States military forces have body fat content standards. In each Service, percent fat is estimated from circumferences and stature.

- Bioelectric impedance is another field technique where the impedance, the conductivity or both are measured and transformed into estimates of relative body fat (Wilmore and Costill, 2004; Brodie, 1988 I+II).

If valuable information about the physical performance capabilities should be used from anthropometric data, percentage of body fat can give such information. If load-bearing capabilities are required, heavier subjects perform even better than lighter ones. But heavy and lean (low body fat percentage) persons have almost the best anthropometric prerequisites (Bilzon et al., 2001; Lyons et al., 2005; Harman and Frykman 1992). Irrespective of task requirements, if two individuals with identical body weight perform at the same task, the leaner person would always have the advantage (Wilmore and Costill, 2004; Vogel and Friedl, 1992).

However, anthropometric measures have to be interpreted in order to cope with different kinds of physical activities. Work that requires muscular strength usually leads to different anthropometric requirements than endurance-orientated tasks. The following paragraph explains how different anthropometric characteristics can affect physical performance.

7.4.2.3 Muscular Strength

Physically demanding tasks are common in day-to-day military activities. These physical demands have changed over the latest decades from a more endurance-orientated to a fast-and-short mode of operation. Thus, physical requirements have to be adapted.

With regard to physical performance, anthropometric measurements can add valuable information for selecting appropriate personnel. For activities that require strength, power, and/or muscular endurance subjects with high amounts of fat-free mass are needed. These soldiers are best suited for military tasks like load bearing or rescue activities using manual stretcher carriage (Bilzon et al., 2001; Lyons et al., 2005; Leyk et al., 2006a,b).

7.4.2.4 Endurance Capacity

In contrast to strength improvements, endurance performance does not improve with increased body mass or muscle mass because extra loading decreases endurance-orientated performance. For endurance activities,

where rate of energy production is a limiting factor, extra load decreases performance. The work performed and energy required is directly related to body weight. Hence, lighter runners use less energy at a given speed in comparison with a heavier peer.

Anthropometric data can give baseline information about the potential endurance capabilities when looking at the parameters body weight and body fat percentage. Thus, from an anthropometric point of view low body weight or BMI-Values in combination with a low percentage of body fat favour endurance performance.

7.4.3 IMPROVEMENTS IN BODY WEIGHT AND BODY COMPOSITION

The modifiable potential of anthropometric measures is limited to body mass and body composition. Body height and other measures of length are intrinsically (genetic) determined. Even if body weight or body composition is predisposed (e.g. gender variations), they can be affected by several lifestyle or environmental conditions.

If anthropometric measures are used for personnel selection or medical assessment processes with regard to physical performance capabilities, body weight as well as body composition should be recorded. Furthermore, gender- and age-specific reference values are necessary and helpful as inclusion/exclusion criteria. Nonetheless, it should be considered that these data have to be interpreted with caution. Subjects with a comparable anthropometric profile will not necessarily perform in the same manner. Endurance capabilities are hard to assess using these anthropometric data because physiological adaptations to endurance training do not necessarily occur with measurable changes in body weight and/or body composition. However, strength and power capabilities could be predicted more accurately, even if body composition data provide no information about regional strength deficits (upper vs. lower body, extensors vs. flexors).

- Increasing fat-free body mass will usually increase strength and power performances. A greater muscle mass generates higher body strength values and is advantageous for individuals who lift and carry heavy loads.
- Decreasing body fat mass is often associated with increased endurance performance. However, a causal relationship to such changes has not been shown. The combination of endurance training and moderate energy intake will lead to an improvement in endurance capability and body weight.

Changes in body weight and body composition of populations in NATO member countries underline the need for improvements in anthropometric measurements in the military. Common definitions and selection criteria as well as training standards are of paramount importance for the near future.

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Section 7.5 – INFLUENCE OF GENETIC VARIATION ON OPERATIONAL PHYSICAL PERFORMANCE

by

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ABSTRACT

A high level of aerobic fitness, muscle strength, and flexibility are essential requirements for strong tolerance of military activities. The individual responses to external influences and the putative side effects of environmental factors are key determinants of maintenance of operational capacities. The considerable inter-individual variations in human responses to either physical exercise, operational stress, or climate strains reflect the interaction of environmental factors (e.g. specific training, nutrition, habitual use) with genetic elements. Several gene polymorphisms have recently been hypothesized to account for the individual responses to external operational strains not usually there and genotype associations have been suggested as at risk for illnesses in response to environmental stress.

7.5.1 THE ANGIOTENSIN-1-CONVERTING ENZYME (ACE) GENE POLYMORPHISM AND HUMAN PERFORMANCE

Recent studies have examined whether genetic background influences physical performance or the trainability of physiological markers linked to performance. The most significant example of this area of research is the possible association between human ACE (kininase II) genotypes and physical performance. ACE is important in controlling the circulatory system and degrades vasodilator kinins, and converts angiotensin I (Ang I) to the vasoconstrictor angiotensin II (Ang II). In addition, local muscle renin-angiotensin systems are important determinants of muscle function (Jones and Woods, 2003). The human ACE gene is located on chromosome 17 and contains a polymorphism consisting of the presence (insertion, I) or absence (deletion, D) of a 287-base pair sequence in intron 16. Hence, three genotypes exist, II, ID, and DD, the distributions of which within a Caucasian population are roughly 25, 50, and 25%, respectively. This polymorphism accounts for up to 47% of the variation in plasma ACE, and DD subjects exhibit high ACE activity, whereas genotype II is associated with low ACE activity in both serum and tissues (Rigat et al., 1990).

Because ACE polymorphism affects serum and tissue ACE levels, and because ACE is involved in the metabolism of substances that affect vascular remodeling, it has been hypothesized that the ACE genotype might account for inter-individual variations in human responses to physical exercise. Previous studies have suggested that the I allele may be associated with some aspects of endurance performance, found more frequently in elite long-distance runners, rowers, and mountaineers (Montgomery et al., 1998). Greater improvement in muscular endurance was observed in male British Army soldiers with ACE genotype II and ID submitted to a 10-week general training program, in comparison with soldiers with ACE genotype DD (Montgomery et al., 1998). Association of the I allele with improved endurance was suggested to derive:

1) From metabolic factors related either from changes in the nature of substrate used or the efficiency or substrate utilization; or
2) From an increase in substrate delivery due to changes in muscle capillarity.

It is likely the relationship between the I allele, and local muscle effects such as the increased half-life of bradykinin and reduced production of Ang II, that may determine the impact of the ACE genotype on performance, via enhanced, endothelium-dependent vasodilatation influencing substrate delivery to the working muscles (Woods et al., 2002).

Taken together, these findings suggest that the variants in the ACE gene may influence physical performance, the response to physical training, or both. Whether low Ang II levels induced by chronic ACE inhibition improve endurance performance and positively affect skeletal muscle metabolic efficiency was examined in an animal model (Bahi et al., 2004). ACE inhibition was not associated with improved endurance performance and oxidative capacity of skeletal muscles. Some experimental evidence showed that the ACE ID polymorphism affects the individual improvement of physical performance in response to a training program. In humans, the influence of the ACE II allele on endurance performance is not mediated by differences in the aerobic training response (Woods et al., 2002), but the mechanisms of the improvements in performance remain largely unknown.

Other studies failed to find a role of the ACE genotype in aerobic performance. The inclusion of athletes from mixed sporting disciplines, which produces phenotypic heterogeneity, often explains the lack of association between I allele frequency and endurance performance (Karjalainen et al., 1999, Rankinen et al., 2000). One study examined whether the association between ACE genotype and physical performance previously shown in selected populations holds true in a cohort drawn from the general population (Sonna et al., 2001). The results of this study showed that in an ethnically and geographically diverse population consisting of US Army recruits drawn from a wide variety of ethnic backgrounds, there is probably no major effect of the ACE genotype on physical performance based on aerobic power or muscular endurance.

Together, these findings fail to demonstrate a strong relationship between the ACE genotype and physical performance in young, healthy individuals from the general population, such as military recruits.

7.5.2 HUMAN ACE POLYMORPHISM AND DISEASES RELATED TO MILITARY ENVIRONMENT

Exertional heat stroke is a fatal risk of hyperthermia induced by exercise performed in a hot climate. A wide range of individual variability exists in normal thermoregulatory responses to exercise in hot environments. The variability in heat tolerance in healthy humans such as soldiers has been shown to be related to various factors, but taken together, all these factors fail to explain the inter-individual variations in heat-stress responses. Therefore, the role played by the genetic endowment on the variability in exercise heat-stress responses has recently been examined (Heled et al., 2004). The allele I of the human ACE gene has been associated with increased heat tolerance during exposure to exercise heat stress. Moreover, there was a dose effect of the existence of the allele I and individuals with ACE genotype II who had the best heat-tolerance results. Mechanisms responsible for this finding remain unclear but could be related to the effects of Ang II on vasomotor function and thermoregulatory response to exercise heat stress. Although these recent data should be interpreted with caution, they suggest that the ACE I allele may be a candidate prediction marker for better tolerance to exercise heat stress and preventing the occurrence of heat injuries.

Medically unexplained fatigue has been shown to occur quasi-epidemically in veterans following the first Persian Gulf War (McCauley et al., 2002). Because the cause of this disorder remains unknown, a genetic predilection to developing unexplained fatigue has recently been considered (Vladutiu and Natelson, 2004). Research suggests that many abnormalities in genes affecting endocrine regulation exert a possible genetic influence in the pathogenesis of medically unexplained fatigue. Moreover, other genetic factors known to affect physical performance in endurance in army recruits have been examined, including the

ACE ID polymorphism (Vladutiu and Natelson, 2004). A lower prevalence of the II genotype, with a concomitant increase in the DD genotype, was shown in Gulf War veterans with medically unexplained fatigue. Although preliminary, these findings suggest an association between medically unexplained fatigue in Gulf War veterans and the ACE ID polymorphism.

Taken together, these findings must be viewed as preliminary and only significant to predicting genetic susceptibility to the adaptive responses to stress (i.e. metabolic, physical, or psychological stress) or to the occurrence of intolerance-related injuries.

7.5.3 OTHER GENE VARIATIONS ASSOCIATED WITH INDIVIDUAL DIFFERENCES IN RESPONSES TO STRESS

This scientific domain is of considerable interest for future research. More than 90 genes or gene variations have been associated with differences in exercise performance and health-related fitness phenotypes (Perusse et al., 2003). Several recent studies examined the association between polymorphisms of local growth factors and cytokines with the adaptability of skeletal muscle following acute resistance exercise. Both ciliary neurotrophic factor and interleukin-6 (IL-6) genotypes have been associated with muscle strength (Roth et al., 2001, 2003). An association between IL-1 gene variations and the acute inflammatory response to resistance exercise has been recently reported, suggesting that cytokine function in response to exercise is, at least partly, genetically regulated (Dennis et al., 2004).

7.5.4 SUMMARY

Many gene polymorphisms likely contribute together to explain the inter-individual variations in the adaptive responses to environmental stresses. Many other gene or cluster gene variations likely cooperate and contribute to determine the individual susceptibility to the development of diseases in response to strains of the operational environment. Improving our knowledge in predicting genetic susceptibility to the development of such diseases would contribute to selecting recruits for specific jobs within the Army, thus promoting health of military personnel.

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Section 7.6 – NUTRITION AS A FACTOR INFLUENCING MILITARY PERFORMANCE

by

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ABSTRACT

Nutrition before, during, and after military operations, can be viewed not only as a means to enhance military performance, but also as a factor negatively affecting the efficiency of military personnel during operations. The availability of palatable food, properly packaged and planned, and application of good feeding practices in the field significantly help to maintain and likely to enhance human performance and morale. These positive factors contribute to the success of military missions. Nutrition during military activities and training, must meet the energy and nutritional needs. Providing a nutritionally inadequate diet, or, in contrast, overfeeding, has deleterious effects on health and performance.

In addition to the acute problems of nutrition in the field during military operations, eating well in garrison prepares to maximize the positive effects of physical and mental training. For civilians, educating military personnel to make appropriate food choices, based on physical activity level helps maintain healthy weight and maximize the effects of military training.

7.6.1 ENERGY REQUIREMENTS DURING MILITARY OPERATIONS

During operations, deployed military personnel may have very different tasks and thus very different energy requirements. Most studies showed that energy expenditure of military personnel generally exceeds that of civilians. In one study, energy requirements of military personnel ranged 2,300 kcal to 7,100 kcal (Tharion et al., 2005). The total energy expenditure of male military personnel averages 4,620 kcal across all activities, military specialties and environments, and is approximately 38% higher than the mean total energy expenditure of civilians.

Military occupational activities determine energy requirements. Members of combat units expended approximately 20% more energy than support soldiers during the same training period. Most studies showed that combat soldiers expend significantly more energy than combat-support soldiers. Total energy expenditure also varies according to the type of mission and environmental conditions. A 15% to 20% increase in energy expenditure has been reported in soldiers deployed to the field in comparison with garrison. This increase in expenditure during deployments and field training is mainly related to an abundance of ambulatory activities, carrying loads, and long workdays are a major factor increasing energy requirements. Military workdays in the field, often exceed 16 hours of activity, while in contrast, most soldiers in garrison work and train less than 12 hours per day.

One of the major problems with nutrition during field activities is that energy intake is unable to match expenditures. Military personnel usually consume insufficient energy, whether they are provided an adequate amount or not. Energy deficit is a constant observation in all field studies. The energy deficit amount varies according to the activity. Inadequate food intake has been attributed to a number of factors, including lack of time, poor ration palatability, menu boredom, lack of water, and decreased appetite.

Other factors, such as lack of specific meal time periods, lack of time to prepare meals, anxiety due to field conditions, play a role in inadequate food intake and energy deficit. Moreover, field studies clearly demonstrated the trade-off between providing sufficient energy for the soldier, versus carrying a lighter load with insufficient energy.

7.6.2 CONSEQUENCES OF UNDERFEEDING

Underfeeding has long- and short-term consequences on health and specific components of physical performance. The consequences of energy deficit on health are well documented and result especially in depression in immune function (Keusch, 2003), and impairment in recovery from illness and injury.

7.6.2.1 Short Term Effects

A short period of underfeeding has deleterious effects on the physiological responses to exercise, such as increased heart rate during aerobic work, and impairment in the subjects' orthostatic tolerance. An impairment in recovery is also reported, with complaints of fatigue, muscle soreness, and weakness after the period of physical work with energy deficit (Montain and Young, 2003).

Muscle strength is affected by an energy deficit; a reduction in muscle strength is reported after 6% body mass loss, with increasingly poorer performance with additional body mass loss. The effects of underfeeding on muscle power are less clear, and, the reductions primarily seen in anaerobic performance have been due to muscle weakness rather than short-term dietary effects. In contrast, the capacity to generate maximal aerobic power appears to be sensitive to underfeeding. Reductions seen in the maximal aerobic capacity have been reported following as little as 2% body mass loss. Alterations in the maximal aerobic capacity are related, at least partly, to a loss of body water. The reduction in aerobic capacity appears as a real consequence of short-term energy restriction, and likely has deleterious effects on physical performance.

Most experiments conducted in the field lead to the conclusion that short periods of moderate underfeeding have only limited impact on the ability of the soldier to perform occupationally relevant tasks. However, most of these studies were composed of relatively small sample sizes, with large within-group variability. It is likely that small but real decrements in performance consequent to underfeeding may have been missed because of lack of statistical power (Montain and Young, 2003). Moreover, mental and cognitive performance is one of the determining factors of military tasks. The effects of underfeeding on such performance has been poorly studied.

7.6.2.2 Long-Term Effects

Prolonged periods of underfeeding clearly lead to a marked reduction in body mass with fat mass decline, and are paralleled by a reduction in muscle strength, and maximal aerobic and anaerobic powers. Recent studies confirmed that a 62-d period of underfeeding resulting from both energy restriction and high total daily energy expenditure has deleterious effects on muscle strength and power (Shippee et al., 1995). Taken together, all studies consistently demonstrate that long-term underfeeding can have detrimental effects on soldier physical performance capability.

7.6.3 COMMON DIETARY GUIDELINES FOR GOOD HEALTH IN GARRISON

Eating well in garrison is essential to prepare the body to be physically fit to endure any condition encountered in the field and to meet the physical and mental demands of military training (Thomas et al., 2001). For military in garrison, the aim is to reach or maintain a healthy body weight. The diet should consist of a healthful assortment of foods that includes vegetables, fruits, grains, fish, lean meat, poultry or beans. Foods that are low in fat and in added sugars should be chosen most of the time. Whatever the food, portion sizes should be sensible to avoid any prolonged alteration of the energy balance.

7.6.4 GENERAL GUIDELINES FOR MILITARY RATIONS

Field feeding is mainly based on military rations that are defined as one day's supply of food. The type of ration is mostly dependent on the type of military mission. The packaging should provide longer shelf life for foods and make the rations more compact and lightweight for ease of carrying. One of the key problems with military rations is preservation of food palatability, and then to favor the voluntary consumption of all components of the individual ration. It is expected that the military rations could comply with the energy and nutrient requirements. An overview of guidelines and design of existing group and individual rations has been previously published (Thomas et al., 2001).

Alterations in the dietary content of macronutrients to improve soldier performance are a matter of discussion. The utility of carbohydrate-electrolyte drinks for sustaining athletic performance is widely accepted. The potential efficacy of liquid carbohydrate feedings has received considerable attention, and all recent studies consistently demonstrated that carbohydrate drinks are an efficient method to increase energy intake in soldiers in the field, and to maintain sustained performance when limited food is available (Montain and Young, 2003) (see below). The potential benefit of fat supplementation to optimize energy availability and to enhance the energy density of the ration has been examined. It appeared that there was no increase in physical performance to supplementing the ration with fat (Hoyt, 1991). Together with other results from non-military sources, military rations should provide adequate energy, mainly from carbohydrate, and protein to sustain metabolism and allow recovery from intense and prolonged exercises.

7.6.5 ARE NUTRITIONAL ERGOGENIC AIDS RECOMMENDED?

A growing list of ergogenic products claim to boost physical and mental performances. Like sportsmen, soldiers may take such supplements because they believe they do not consume enough food to meet their nutritional needs, or they want to improve their ability to meet the challenges of field training. Usually, garrison meals and military rations can provide enough energy in all operational situations. The best strategy for optimal health and military performance is to ensure availability of food and fluids, and to promote their consumption in the field. Several studies have been performed to determine whether creatine supplementation may help soldiers become more capable of performing their military operational tasks (Montain and Young, 2003). While creatine may have some ergogenic effects that improve performance on tasks requiring high muscular power, creatine has not been shown to enhance performance on occupationally relevant tasks (Bennett et al., 2001). The potential use of some specific amino acids, antioxidant vitamins, and trace elements under field conditions needs to be addressed to reduce the incidence of illness and to enhance recovery from illness or injury, especially when dietary intake might be compromised.

7.6.6 FLUID REPLACEMENT DURING MILITARY OPERATIONS

Soldiers can survive for extended periods with little or no food, and they can use supplements to meet their physical needs for even greater periods. Fluid replacement is the only way to avoid dehydration, reduce the risk of heat casualties, and thereby minimize military performance degradation. Water is the one item that the soldiers must have to remain combat effective; there are no alternatives. While a soldier can last several days without nutrition, in many environments he can only last hours before experiencing debilitating and life-threatening effects of dehydration.

7.6.6.1 Fluid Replacement

Dehydration in excess of 3% of total body water markedly reduces military performance and increases the thermal stress of exercise (Sawka et al., 1996). Drinking is the only way to replace fluid loss and prevent

dehydration. Guidelines for fluid replacement provide recommendations for fluid replacement based on climatic conditions (Kolka et al., 2004). Actual guidelines have been shown to successfully minimize the incidence of significant serum sodium loss without increasing the risk of dehydration for soldiers in the military training environment. Available fluid replacement tables include activity level (energy expenditure) and upper limits for hourly and daily fluid replacement to provide safe guidelines that would reduce the incidence of hyponatremia (defined here as serum sodium concentration less than 135 $mEq \cdot L^{-1}$) without increasing the incidence of dehydration in a military training environment (Montain et al., 1999).

During military training, water is the primary rehydration beverage, and the electrolytes replaced during meals as daily sodium intake for garrison or field diets are sufficient for replacing most sodium losses from sweat. Other electrolytes lost in sweat are potassium, calcium, and magnesium. Including sodium and other electrolytes can be an effective electrolyte replacement during prolonged periods of profuse sweating in hot weather, especially when meals are not available.

7.6.6.2 Potential Use of Dietary Liquid Carbohydrate Supplementation

Many studies conducted in the field provided evidence that carbohydrate-electrolyte drinks provide an accessible source of energy, which can be of advantage when limited food is available during prolonged military training (Montain and Young, 2003). The benefits of carbohydrate-electrolyte drinks were demonstrated by the ability of soldiers to sustain both uphill running and marksmanship performance in hot weather (Montain et al., 1997). The effectiveness of carbohydrate drinks is maximized with feedings during both rest and military exercise. Taken together, these studies demonstrate that both energy intake and the timing of intake are important variables for optimizing soldier performance. The use of such drinks is important for sustaining physical and mental performance by providing both adequate fluids and energy quickly available during activity.

7.6.6.3 Water Availability, a Key Issue in the Field

Water availability during military operations affects the capacity of soldiers to carry heavy loads. Loads are rapidly becoming unmanageable, and a significant contributor to this problem is the soldier's need for water (DuPont and Dean, 2004). As temperatures climb, the soldiers carry even more water to compensate for the loss of body fluids.

Water availability affects drink packaging and design, re-supply operations, and soldier load. Soldiers cannot be expected to carry weights greater than 50% of their body weight. These weights have a negative impact on soldier endurance, situational awareness, and the ability to respond quickly and accurately to a threat (DuPont and Dean, 2004). A significant portion of this weight is attributed to the water that personnel are forced to carry. The Army must examine alternatives for supplying the soldier with water, in all environments, and across the full spectrum of operations.

7.6.7 IMPACT OF ENVIRONMENTAL CONDITIONS ON NUTRITIONAL NEEDS

Nutritional and fluid requirements during military operations vary according to environmental conditions.

7.6.7.1 Hot Environments

A hot environment has no detectable effect on military personnel's energy expenditure, and thus does not affect energy intake. The most critical need in a hot environment is adequate fluid replacement.

Total energy expenditure values observed in infantry soldiers conducting combat training during the summer were very similar to those measured during training in the cold (Tharion et al., 2005). Energy

expenditure has been shown as lower in hot than in cold environments, likely because military personnel might perform less work in hot environments.

In hot environments, heavy work increases sweat rates and the likelihood of dehydration and other heat injuries. Failure to replace fluid lost through sweating can lead to dehydration and increase the individual's susceptibility to heat injury. Normal thirst does not ensure one will drink enough fluid voluntary to replace fluids lost through sweat. Because soldiers are unlikely to drink enough fluids voluntarily; leaders have to take an active role in minimizing the risk of dehydration and must enforce policies to insure that they consume enough fluids.

The impairment of food intake expected during military activities in the field can result in decreased salt intake necessary to replace minerals lost through sweating. Food is also a source of water and underfeeding can affect fluid replacement. Lastly, more than half of all fluids are consumed at mealtimes. If soldiers skip meals, the amount of fluid taken in will also decrease dramatically (Thomas et al., 2001).

7.6.7.2 Cold Environments

Total energy expenditure increases during military activities in a cold environment. A 30% increase in energy expenditure has been reported when military activities are performed under cold-weather conditions (Hoyt et al., 2001). The greater energy expenditure values are partly related to a longer, more physically demanding workday than during warmer weather exercises.

When working in cold environments, the weight of winter clothing can increase energy demands by 16% compared with demands of wearing desert clothing (Tharion et al., 2005). If clothing is insufficient, shivering can increase metabolic demand by as much as 430 $kcal \bullet h^{-1}$. The location of the weight of clothing or equipments on the body also influences total energy expenditures. For example, wearing heavy boots increases total energy expenditure to a greater extent than carrying the boots in a backpack, close to the center of mass. Energy expenditure of military personnel is thus increased when soldiers use or carry specialized winter equipment, and still increases as much as 30% for locomotion on hard-packed snow and up to 500% for deep snow (Tharion et al., 2005).

Military personnel often become dehydrated during cold weather operations. Dehydration can result from problems with frozen water and eating field rations with lower water content than most garrison foods. Thereafter, dehydration affects appetite and leads to fatigue and weakness. Moreover, it is suggested that dehydration can potentially increase the risk of frostbite, as a result of fatigue and mental changes which contribute to poor judgment and accidents. Thus, management of fluid intake should also be a major concern for leaders, to maintain adequate hydration and prevent cold injuries.

7.6.7.3 High Altitude

Many factors can explain the increase in energy expenditure that is often reported for military activities at high altitude. Hypoxia increases total energy expenditure, as do other factors, such as carrying specialized equipment, rough terrain, and additional clothing frequently worn at high altitude. High winds, snow, and cold temperatures also contribute to increased energy expenditure (Tharion et al., 2005). Military activities performed in this environment add to the energy cost above that already required when military personnel are exposed to the cold and snow at sea level. In addition to the specific effects of steep and mountainous terrain, high-altitude exposure increases basal metabolic rate, ventilation rate, and decreased ability to sleep. Taken together, energy requirements for high-altitude operations can be increased up to 10% above sea- level requirements.

Weight loss is a common observation during hypoxia exposure, mainly related to a loss of appetite, limited food availability, and difficulty in food preparation. During exposure to altitude, hypoxia is the

major factor negatively affecting food intake. The weight lost consists of both body fat and lean tissue. At very high altitudes, lean tissue loss predominates. Accompanying the weight loss, are fatigue, loss of strength, and psychological changes, all of which interfere with mission success. Increased energy expenditure associated with loss of appetite results in a marked alteration of energy balance.

Carbohydrate supplementation improves physical performance and mental efficiency during military activity; carbohydrates are the preferred energy source at altitude, replenishing muscle glycogen stores and preventing protein degradation and amino acid oxidation. The potential use of carbohydrate-electrolyte drinks has been examined during sustained physical exercise at altitude (Montain and Young, 2003), with varying efficiency on performance. However, using carbohydrate-electrolyte drinks during military exercises in altitude, undoubtedly contributes to improved carbohydrate availability, the preferred energy source under these conditions.

The body's requirement for fluids is very high at altitude, often exceeding 4 liters per day. This is related to increased water loss from the lungs and urinary loss due to the diuretic effects of altitude and cold. Difficulties in consuming adequate fluids at altitude due to lack of potable water, restricted water availability by cold temperatures, and alterations of thirst all affect the body fluid balance.

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Section 7.7 – EFFECTS OF HEAT ON OPERATIONAL PHYSICAL PERFORMANCE

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7.7.1 EFFECTS OF INCREASED AMBIENT TEMPERATURE AND HUMIDITY

7.7.1.1 Body Heat Exchange

The normal comfort range for the body is an air temperature of 22°C to 25°C, when resting, lightly clothed, in a very light breeze with no radiant heat load (Anonymous, 1974, cited in Goldman 2001). Under these conditions, the body is able to dissipate the heat produced by resting metabolism to the environment and the body core temperature is stable at its resting value. The net heat stress is zero. The situation changes markedly when we begin to perform physical work.

The human body has been estimated to have an efficiency of 10 to 25% when carrying out physical work (Gonzalez, 1988, p. 176; McArdle, Katch and Katch, 1991). As a result, most of the energy that is expended to support physical work appears as heat within the body. The ability to continue to perform physical work depends on the ability to lose the excess metabolic heat produced. Most of this heat is exchanged at the body surface.

Heat can be lost from the body by several methods:

a) Radiation;

b) Conduction;

c) Convection; and

d) Evaporation.

Radiative heat loss involves the transfer of heat through electromagnetic waves to surrounding objects (walls, floors, trees, the sky). Conductive heat exchange is transfer of energy by direct contact with surfaces. Convective heat loss occurs through the transfer of heat to fluids moving across the surface of the body, usually air or water. Evaporative heat loss occurs when the body provides the heat needed to vaporize liquid water from the skin. Water may appear on the surface of the skin by passive movement from the interior of the body. Such water is known as insensible perspiration. Water may also appear at the skin surface as a result of active transport by the sweat glands. This water is known as sensible perspiration and contrasts with insensible perspiration in that the water accumulates in sufficient volume to be felt on the skin. A small amount of evaporative heat loss also occurs through the vaporization of water into the exhaled air.

In general, as the ambient temperature and humidity rise above neutral conditions (in which heat balance is maintained), the ability to lose heat to the environment decreases. Heat loss by radiation depends upon

the environment having less thermal energy than the body. If the objects have less thermal energy than the body, heat can be lost the environment. Heat losses through conduction or convection are a function of the difference in temperature between the skin and the ambient air. Heat loss through evaporation depends on the water content of the air surrounding the skin (i.e. the relative humidity).

The environmental ambient temperature and relative humidity influence the effectiveness of these methods of body heat loss. For example, in the hot dry conditions of the desert, the temperature of the air and the surrounding objects is often greater than that of the body surface. The sun is the source of radiant heat, either by direct irradiation of the body (insolation), or indirectly in the form of heat waves that are reflected from objects or radiated from objects that have been heated by the sun. The sum of all the sources of radiant heat in the environment is usually measured as a black globe temperature (the temperature of the air inside a black metal sphere, which is placed in the environment being measured). Under hot desert conditions, heat cannot be removed from the body by radiation, conduction, or convection. In fact, under such conditions, heat exchange with the environment by these routes would result in a gain in body heat. Because desert air is dry, we are able to maintain our core temperature within normal limits because of our ability to lose heat by evaporation. The water that accumulates on the skin from sweating vaporizes into the dry air, extracting the heat of vaporization from the body.

In high-humidity (e.g. jungle) environments, the ability to lose heat through evaporation of sweat can be greatly decreased. As the temperature increases, the ability to lose heat through radiation, conduction, and convection is also decreased. It is possible under hot, humid conditions to reach conditions wherein heat loss is impossible. Such conditions generate what is referred to as uncompensable heat stress. Under those conditions one must move into a more-temperate environment or suffer a heat injury.

Goldman (2001) listed 6 “agents” of heat effects:

1) Ambient air temperature;
2) Air motion or wind velocity;
3) Air relative humidity;
4) Mean radiant temperature (globe temperature);
5) Metabolic heat produced; and
6) The clothing insulation (clo) and moisture permeability.

Goldman also provided a set of equivalences by which one can evaluate the effects of change in these agents:

- A 10% change in relative humidity is comparable to a 0.28°C change in ambient temperature.
- A 0.1 $m \cdot s^{-1}$ change in wind velocity is equivalent to a 0.55°C ambient temperature change (up to 2.8°C).
- A 1°C change in radiant temperature is equivalent to a 1°C change in dry air temperature.
- 0.1 clo (1 clo = 0.155 $m^2 \cdot °C \cdot watt^{-1}$)[1] of additional clothing is equivalent to 0.56°C in ambient temperature up to a work rate of 2.5 MET of activity, and 1.1°C at greater activity levels.
- A 25 $kcal \cdot h^{-1}$ is equivalent to a 1.67°C change in ambient temperature.

[1] Clo: The “clo unit” is a unit of thermal insulation on the body that is afforded by the clothing that is worn. The unit is based on the insulation of a standardised “suit.” See Section 7.6.

7.7.1.2 Physiological Response to Increased Body Temperature During Exposure to Compensable Heat Stress

In response to an increase in body core temperature, cardiac output is enhanced through increases in heart frequency and stroke volume. Blood flow to the skin is raised. This raises the temperature of the skin to aid in the exchange of heat with the environment, and boosts the blood flow to the sweat glands to raise availability of fluid for sweat production. Additionally, there is an increase in blood flow to the active muscles, which not only augments the supplies of oxygen and metabolic substrates, but also increases the rate of heat removal from the body (Sawka and Wenger, 1988; Werner, 1993).

7.7.1.3 Adaptation to Hot Environments

In response to repeated exposures to hot environments, several adaptive changes take place. Cardiovascular changes lead to a decrease in heart rate at any given exercise rate. Blood volume increases, at least initially. The core temperature at which skin vasodilatation occurs decreases. The rate of increase in skin blood flow per unit of core temperature rise increases, and, hypothetically, the maximal amount of skin blood flow is greater (Pawelczyk, 1993). The onset of sweating takes place at a decreased core temperature relative to that observed prior to acclimation, and the volume and rate of sweat production are increased for the same thermal exposure. In addition, the composition of the sweat changes, becoming more dilute. With these changes, there is an accompanying decrease in core temperature for a given work rate.

Acclimation to the heat is produced by repeated exposures sufficient to raise the core temperature and provoke at least a moderate degree of sweating (Goldman, 2001; Wenger, 1988). Moderate exercise in the heat for 1-hour each day is adequate to provoke an adaptive response in an unacclimatized person. With such a program, acclimatization can be achieved in 7 to 10 days.

7.7.2 EFFECTS ON PHYSICAL PERFORMANCE

One of the keys to maintenance of physical performance is the removal of heat from the working muscles. It should be clear that as the ambient temperature increases the ability to transfer heat to the environment is decreased, and the work rate that can be supported is decreased. According to data provided in (Goldman 2001), it is estimated that for every 1°C of effective temperature (a temperature scale developed to provide equivalent temperature sensation in a variety of dry air, relative humidity, and wind speed conditions) the 4-hour tolerated work rate decreases by 12.35 $kcal \cdot h^{-1}$.

One factor underlying this decrease in work capacity is that there is increasing competition for blood flow from the muscles, which requires blood to continue to perform work, and from the skin, which requires increased blood flow to support heat dissipation. Eventually, cardiac output becomes limiting (Pawelczyk, 1993; Sawka and Wenger 1988), and heat loss cannot be maintained at sufficiently high levels. If heat dissipation cannot keep pace with heat production, heat will be stored in the body, and core temperature will rise. The situation of rising body heat content and body core temperature has been shown to be related to onset of fatigue (González-Alonso et al., 1999). The rise in body temperature and heat content can also result in disruption of brain function (heat stroke).

A second factor is that the competition for blood flow is exacerbated by the fact that cooling the body by evaporation is associated with the fluid loss. Work in the heat is often accompanied by dehydration. Fluid is lost in sweat production, which can reach rates of 2 to 3 L of sweat per hour, at least for short periods of time. Loss of fluid contributes to decreased ability to adequately supply muscles with metabolic substrate, and to adequately transport heat from the muscles to the skin (Werner, 1993). It can also lead to circulatory collapse (heat exhaustion). The effects of dehydration on performance are discussed in a separate section of this chapter.

The phenomena described above suggest that problems with the heat result in circulatory problems, and that it is endurance performance that is compromised. There does not appear to be strong evidence of direct effects on muscle leading to decreased performance. Effects of increased ambient temperature have been shown to affect sprint performance (Drust et al., 2005) and isometric strength (Morrison, Sleivert and Cheung, 2004). However, in each of these studies, the authors concluded that the effects are centrally mediated and associated with increased core temperature.

7.7.3 STEPS TO AMELIORATE THE EFFECTS ON PERFORMANCE

If one anticipates the requirement to carry out physical work in the heat, one should make every effort to acclimate the body to such work. A program of endurance exercise in moderate heat can help accomplish this goal.

During work in the heat, it is important to stay as well hydrated as possible. While fluids cannot be taken up from the gut at rates that match maximal sweating, fluid intake can help delay the development of severe dehydration.

Clothing interferes with the body's ability to lose heat. Clothing, by virtue of its insulative and water-permeability properties, can decrease heat exchange between the skin and the environment. It is important to wear clothing that is as light and water permeable as possible when working in the heat. Current military operations often demand wearing body armor or even chemical, biological, radiological protective suits during operations in the heat. This equipment offers a substantial barrier to heat loss from the body. When wearing such gear, one must decrease the work rate to a level that can be sustained while wearing such gear, or must limit the work period to one wherein body heat storage does not become dangerously large.

Portable cooling systems, such as ice vests or liquid-cooled garments, can also be used to prolong work in the heat. However, these systems are often bulky, heavy, and difficult to "recharge" in the military operational environment.

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Section 7.8 – EFFECTS OF COLD ON OPERATIONAL PHYSICAL PERFORMANCE

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7.8.1 THREATS AGAINST OPERATIONAL PHYSICAL FITNESS IN A COLD ENVIRONMENT

In military operations soldiers are often exposed to various stressors, such as prolonged and strenuous physical exercise, sleep deprivation, and energy and fluid deficiency. In cold environments, countermeasures against these stressors are more laborious to perform than in moderate climates. Some of the countermeasures are stressors themselves, like the weight of cold protective clothes and other equipment or decreased dexterity caused by gloves. Cold-weather injuries are additional stressors related to operations in cold environments. This chapter reviews how cold environment affects physical performance, the physiology behind these effects, and how soldiers' physical fitness can be maintained in these conditions.

7.8.2 FINGERS IN COLD

Hand and finger skin temperatures are dependent on physical activity and thermal balance, thermal insulation of handwear, ambient temperature, wind, contact with cold objects, as well as wetting of handwear, hands, or fingers.

The risk of frostbite is low in ambient temperatures above –10°C. The risk is considerable at –20°C and pronounced at –25°C (Danielson, 1996; Joupperi et al., 2002). Frostbite is the end point in the series of adverse effects of tissue cooling. Lowered manual performance, cold sensations, cold pain, and numbness occur before frostbite and therefore are much more common than frostbite. Manual performance begins to decrease at finger skin temperatures of 30°C and weakens steeply below 13°C. Cold pain is experienced at skin temperatures of 13°C and numbness starts at skin temperatures below 7 to 8°C (Enander, 1984; Heus, Dannen and Havenith, 1995). Rintamäki et al., (2004) reported finger temperature measurements in 70 subjects in different winter weather conditions in Finnish military using standard handwear.

They selected a finger temperature of 13°C (temperature at which manual performance begins to decrease deeply) as the limit of serious deterioration of manual performance, and observed that in ambient temperatures between –20 and –30°C finger temperatures were 69% of operation time under 13°C. Finger temperatures were under 7°C 20% of operation time under 7 °C when fingers are already numb. These findings emphasize the important role of adequate handwear in winter military operations. Rintamäki et al., (2004) also observed that finger warming was achieved at core temperatures above 37.6°C, emphasizing the role of physical activity and whole-body thermal balance in maintaining sufficient finger temperature.

Contact cooling usually occurs with skin contact with metal surfaces. Even thin gloves or thin surface coating with material of low thermal conductivity (e.g. plastic) remarkably reduce contact cooling and the risk of contact frostbite (Havenith, Heus and Dannen, 1995).

7.8.3 DEXTERITY

Finger dexterity starts to decrease strongly below a hand skin temperature of 15°C (Dannen, 1993). Skin-receptor sensibility to touching shows only minor impairment between skin temperatures 25 to 8°C. A nervous block occurs at skin temperature of about 6°C. Thus at skin temperatures of 8 to 6°C the skin sensitivity drops rapidly (Morton and Provins, 1960; Dejong Hershey and Wagman, 1966).

Nerve conduction velocity reduces quite linearly between temperatures of 36 to 23°C (Morton and Provins, 1960), and somewhat deeper below 20 to 25°C. In general, nerve conduction velocity decreases 1.5 m/s per 1°C. A nervous block occurs at nerve temperatures below 10°C (Vangaard, 1975; Paintal, 1965; Basbaum, 1973).

Static endurance work with hands shows the best performance at a muscle temperature of 28°C, whereas the best muscular temperature for a short-term maximal contraction is 38°C (13). At lower temperatures, both maximal force and endurance time decrease rapidly. Maximal static force declined 66% from the initial value in 10°C bath water (Clarke, Hellon and Lind, 1958).

Data about the effects of temperature in joints and tendons are inconclusive but suggest that joint temperature below 24 to 27°C dexterity is compromised due to stiffening. Conclusively, it seems that the reduction in manual dexterity caused by cold is mainly due to cooling of joints and muscles.

7.8.4 ACCLIMATIZATION TO COLD

Although there is no conclusive evidence to support the role of cold acclimatization, the literature suggests that continued cold exposure leads to increased physical performance because the thermal environment is perceived as less uncomfortable. Manual dexterity and performance in cold is maintained better due to reduced cold-induced vasoconstriction. Shivering response is attenuated in repeated experimental cold exposures (Young, 1966; Castellani et al., 2003).

However, it seems that the physiological effects of cold acclimatization are so small that they have no practical importance for physical performance in cold environment (Young, 1966). Adaptation in the form of learning to live, work, and move in cold environments is the key element for ensuring good performance in cold environments.

7.8.5 HYPOTHERMIA

The danger of hypothermia is obvious when related to cold-water immersion or insufficient thermal insulation of clothing, and the countermeasures are obvious. During physical exercise the amount of

clothing should be such that sweating would be minimal. During pauses the amount of clothing should be sufficient to ensure thermal comfort. However, in combat situations it is not always possible to adjust the amount of clothing, thus resulting in excessive sweating that can rise even to 3 to 4 $L \cdot h^{-1}$ (Young et al., 1998) and lead to compromised thermal insulation of clothing.

When considering the role of hypothermia in maintaining operational physical performance, the main problem seems to be protection against cold after exhaustive physical work. Young and co-workers (1998) reported of increased susceptibility to hypothermia associated with prolonged periods of high-intensity exertion, negative energy balance, and sleep deprivation. They studied their subjects immediately after a 9-week Ranger training course, after a 48-hr recovery, and 16-week recovery periods. During the training course the average weight loss was 7.4 kg. In an experimental cold exposure the core temperature decreased in the tests performed immediately and 48 hr after the training course, but not 16 weeks after the course. The set point for the shivering thermogenesis was lower immediately after the training course than after 48 hr or 16 weeks of recovery. Young and co-workers (1998) concluded that thermal balance was weakened during the training course due to loss of insulative body fat and suppressed thermogenic response to cold. The latter was normalized after 48 hrs of recovery. In a study of 48 hrs of sustained operations, Castellani et al., (2003) also reported a reduced mean body temperature threshold for the onset of shivering thermogenesis. The subjects had also lower core temperatures associated with enhanced vasoconstrictor response and no change in heat debt, suggesting insulative acclimation.

When soldiers rest after fatiguing physical work they may fall asleep and not awaken when they begin to shiver. These voluntary movements increase muscular heat production and can elevate body temperature. In mild hypothermia (33 to 35°C deep body temperature) psychological confusion develops, endangering rational behavioral responses, which include seeking or building shelter against cold and wind, making fire, continuing voluntary movements at an intensity sufficient to prevent shivering, and keeping their clothing dry. Soldiers should be aware of the minimal environmental temperature in which they can sleep safely in their standard equipment when dry or wet. These safety limits depend on the quality of the equipment.

7.8.6 DEHYDRATION IN COLD

The effects of dehydration on physical performance in warm or hot environments are well recognized. In cold environments the threat of dehydration for physical fitness is equally important. Fluid intake tends to decrease in cold-weather operations for several reasons. In subzero temperatures the drinking fluids are prone to freeze, and melting them is time-consuming, leading to unavailability of drinking fluids. The drinking fluid is not palatable if it is very cold. Soldiers may also reduce fluid intake intentionally because urination can be troublesome in heavy winter clothing. Soldiers not used to operations in cold environments often tend to wear too heavy clothing causing excessive sweating that promotes dehydration.

Moderately intense activity in moderately (1 to 3°C) cold weather requires a fluid intake of 2.7 L per day (Murray 1995; O'Brien et al., 1996) for maintaining body fluid balance. For monitoring, dehydration recommendations of urine specific gravity >1.029 and osmolality >1052 $mOsm \cdot kg^{-1}$ have been suggested, corresponding with the dark yellow color of urine (Wyannt and Caron, 1983; Armstrong, Maresh and Castellani, 1994). Dehydration of 2 to 5% of body weight has been noted (Coyle, 2004) as better tolerated in moderate (20 to 21°C) than in hot (31 to 32°C) environments. However, in military operations the negative effect of dehydration on physical performance should not be neglected because the effective thermal insulation of winter clothing tends to raise the body temperature to hyperthermic levels. Rintamäki et al., (Rintimäki et al., 1995) observed that dehydration of about 3% of total body weight resulted in about a 10% reduction in maximal working time but not in maximal oxygen uptake in a maximal exercise test done in a 15°C environment (after spending 1 hr in –15°C). At a submaximal work level (125 W)

oxygen consumption was about 25% higher in dehydrated subjects as compared with the test repeated after correction for dehydration. In military operations with moderately intense activity in the cold or moderately cold, daily water need seems to be between 2 and 3 l (O'Brien et al., 1996; Wyannt and Caron, 1983; Rintimäki et al., 1995; Welch, Buskirk and Iampietro, 1959).

7.8.7 ENERGY BALANCE

In military operations, nutritional energy needs appear to depend primarily on physical activity level. The additional effect of cold environments is relatively small (McCarroll, Goldman and Denniston, 1979). However, a cold environment increases energy needs indirectly by making many physical tasks more laborious and time-consuming and by making it necessary to carry different types of cold-protective equipment and fuels. McCarroll and co-workers reviewed the extra energy cost due to wearing cold-protective garments in winter terrain (McCarroll, Goldman and Denniston, 1979). When compared with walking on blacktop roads, energy expenditure was reported to be 1.3-fold when walking on hard-packed snow and 5-fold when walking in deep snow. The energy cost of walking in soft snow (30 cm) reached 16 kcal•min^{-1} when the speed was 4 km•h^{-1} and load 9 kg. Snowshoeing in unbroken snow at a speed of 3.7 km/h and carrying load of 5 kg increased energy costs to 12 to 13 kcal•min^{-1}. Skiing on a packed flat trail at 4.5 km•h^{-1} and carrying a load of 15.4 to 19.8 kg caused an energy cost of 7.4 kcal•min^{-1}. Raising the speed of skiing to 10.5 km•h^{-1} increased energy cost to 14.4 kcal•min^{-1}. Burstein et al., (1996) reported that the load carried by Israeli soldiers was 42 kg in the winter and 35 kg in the summer, the difference reflecting the weight of cold-protective personal equipments. The daily energy expenditures were 4281 kcal in the winter and 3937 kcal in the summer. The energy need of infantry soldier has been reported to be about 4000 kcal•day^{-1} (Jones et al., 1993), and during heavy physical efforts up to 6500 kcal•day^{-1} (Stroud, Coward and Sawer, 1993). A 1985 US Army regulation recommended 4500 kcal in cold environments (Department of the Army, 1985). In the literature there is no agreement about the proportions of carbohydrates and fats in the diet that would be optimal in cold environments (Stocks et al., 2004). However, it seems that the palatability of food in cold is important for sufficient energy intake (Edwards, 1991).

7.8.8 COLD WEATHER INJURIES

Cold weather injuries include hypothermia, chilblains, immersion foot and frostbite. Because most frostbite occurs in feet and hands it can significantly reduce a soldier's physical performance (DeGroot et al., 2003). In the US Army the incidence of cold weather injuries treated in military hospitals has reduced radically during 1980 to 1999. The yearly rate of hospitalizations due to all types of cold weather injuries in 1985 was 38.2 per 100,000 soldiers and 0.2 per 100,000 in 1999. For frostbite, the yearly rate of hospitalizations was about 14 per 100,000 soldiers in 1980 and less than 0.2 per 100,000 soldiers in 1999. This positive development can be explained by multiple factors. Personal equipment has become better in protecting against cold, and cold weather training has become more effective. Closing or downsizing US Army installations in northern latitudes and treating the patients in open care and hospitalizing only the severest cases have also affected the number of hospitalized soldiers with cold weather injuries statistics. African-American men and women were injured approximately 4 times and 2.2 times, respectively, more frequently than Caucasian soldiers.

Between 1976 to 1989 the annual incidence of frostbite in Finnish Defence Forces was about 4 per 1000 conscripts. Thirty percent of the frostbites were in fingers, 27% in toes, 26% in earlobes, and 10% in the nose. Ninety five percent of the frostbites occurred when the temperature was less than –15°C. Wet footwear increased the risk of frostbite in toes 6.5-fold (unpublished report). Modernization of soldiers' personal winter equipment has reduced the incidence of frostbite in Finnish military, but no statistical data are available for the present situation.

7.8.9 SUMMARY OF COLD WEATHER INJURY RISK FACTORS AND COUNTERMEASURES

In preventing cold weather injuries the first step is to understand the conditions that cause an increased risk of cold weather injuries: temperature below 5°C in dry conditions or below 15°C in wet conditions. The strong cold potentiating effect of wind is important to understand. The risk of cold weather injuries is also increased by inadequate clothing, shelter, and nutrition, sleep deprivation, little experience in cold weather operations, previous cold weather injuries, and low physical activity.

Key countermeasures are adequate shelter against cold and wind, as well as adequate clothing and the ability to use the cold-protective clothing correctly. During low physical activity cold-protective clothing must be sufficient to keep muscular shivering away; during heavier physical activity, the thermal insulation must be low enough to prevent excessive sweating. Clothing must be dry, this is especially critical in footwear and socks. Therefore, it is mandatory that soldiers have with them spare inner clothing layers, have the facilities to dry the wet pieces of clothing, and can keep their spare clothing dry. Protection against and management of cold injuries is described in detail in two recent documents: TB MED 508 "Prevention and Management of Cold-weather Injuries" (2005), and NATO RTO-MP-HFM-126 "Prevention of Cold Injuries" (2005), as well as a handbook for medical officers (US Army Research Institute of Environmental Medicine, 1993).

7.8.10 MENTAL PERFORMANCE

Marked whole-body cooling that causes a reduction in deep body temperature of 2 to 4°C impairs memory and concentration (Coleshaw et al., 1983; Giesbrecht et al., 1993; Lockhart et al., 2005). Body hypothermia (<35°C) is associated with symptoms of confusion, amnesia, and decreased alertness and consciousness. However, the results of studies using moderate, non-hypothermic cold-exposure have been inconsistent: decreased, unchanged, or improved mental performances have all been reported (Palinkas, 2001; Mäkinen, 2006). Mental performance seems to be impaired more by fast cooling than by slow cooling (Ellis, Wilcock and Zaman, 1985). In their study Marrao et al., (2005) observed during a 9-day cold weather operation no serious decrements in mental performance when normal deep body temperatures and hydration levels were maintained. Thus, we concluded that the cold environment itself does not compromise mental performance as long as adequate cold protection is maintained.

7.8.11 SUMMARY

It is essential that leaders train in advance their military units to operate and maintain physical performance in cold environments. Main training goals are:

1) Soldiers learn the correct use of personal cold-protective equipment (especially handwear and footwear);
2) They understand what are sufficient energy and fluid intake; and
3) They are aware of the danger of cold weather injuries and are trained to start countermeasures immediately when they observe the first signs or symptoms.

Military personnel must be aware that physical exhaustion is an important risk factor for cold weather injuries that often causes incapacitation of the soldier.

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Section 7.9 – EFFECTS OF ALTITUDE ON OPERATIONAL PHYSICAL PERFORMANCE

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7.9.1 BACKGROUND

Military operations in mountain terrain can be associated with environmentally related medical problems and performance decrements that can have significant impact on mission attainment. Military personnel may be more at risk for problems than civilians, because military operations can increase exposure to harsh conditions, such as *hypobaric hypoxia, cold, insolation, dry air, and complicated mountainous relief etc.* In addition, external stresses such as increased load carriage and rugged terrain features, unpredictable weather conditions, snow-covered ground, and mountain sickness can lead to decreases in functional capacities. In mountainous regions, the load carried will almost certainly increase – because of the additional weight of protective clothing and technical equipment. Military physical performance in the mountains may also be adversely affected by sleep deprivation, increased physical and/or emotional stress, caloric and fluid restrictions, reduced visibility, equipment failures, inadequate communications, and lack of specialized medical equipment.

Two characteristics of military operations are particularly important in shaping the interaction with mountain environments: the wide range of activities associated with military operations, and the frequent lack of choice as to when and where to participate in those activities. Behavioral and psychological incompatibility of personnel may cause great harm to a soldier's health, and his ability to work. It can also cause large social and economic losses. Therefore, when forming military units including border guards to serve at high altitude, it is extremely important to screen for individuals who are at risk to get "adaptation" sicknesses.

7.9.2 DEFINITION OF TERRESTRIAL ALTITUDE

The concept of high altitude is an arbitrary one. It can mean an elevation of 1500 m. Terrestrial altitude can be defined as follows:

- Intermediary altitude: 1500 to 2500 m; physiological changes due to hypoxia are detectable, but arterial oxygen saturation remains above 90%; altitude illnesses is possible (Mason et al., 1994).
- High altitude: 2500 to3500 m; altitude illnesses are common with rapid ascent to above 2500 m.
- Very high altitude: 3500 to 5800 m; arterial oxygen saturation falls below 90%; altitude illness is common and marked hypoxemia occurs during the exercise.
- Extreme altitude: above 5800; further successful acclimatization cannot be achieved. Progressive deterioration occurs, and survival cannot be maintained permanently. Marked hypoxaemia occurs at rest.

At increasing altitudes above sea level, barometric pressure (PB) decreases and with it the partial pressure falls. At the summit of Mont Blanc (4807 m) the partial pressure of oxygen (PO_2) is about half of that at sea level, and on the summit of Mount Everest (8848 m) it is one third of sea level pressure. For a given

altitude, barometric pressure is higher at the equator than at the poles and is higher in summer than in winter. The PO_2 in the atmosphere falls as PB falls. Temperature and ultraviolet radiation also change at high altitudes: temperature decreases with increasing altitude at a rate of approximately 6.5°C per 1000 m and UV radiation increases approximately 4% per 300 m due to decreased cloudiness, dust, and water vapor. In addition, as much as 75% of ultraviolet radiation can be reflected back by snow, further increasing exposure at high altitude. Survival in high altitude is dependent on adaptation to and protection from each of these elements.

7.9.3 PHYSIOLOGICAL RESPONSE TO ALTITUDE

The major effects of high altitude on humans are related to changes in PB and subsequent changes in the ambient pressure of oxygen.

The inspired oxygen partial pressure (PIO_2) falls with increasing elevation. This decline has almost linear character: 100 m terrestrial elevation causes a decrease of PIO_2 1.18 mm. (West et al., 1980). PIO_2 149 mm. at sea level and 43 mm Hg at Mount Everest. Although the major determining factor of PIO_2 is PB, and body temperature, that determines the partial pressure of water vapor (PH_2O), also can affect PIO_2.

Oxygen must constantly be transported from the atmosphere through the respiratory system to the tissues' mitochondria in insufficient quantities to meet tissue demands.

Hypobaric hypoxia causes altitude illness and physical and cognitive performance decrements. At high altitude, lowlanders (natives or acclimatized inhabitants of low-altitude regions) are incapable of as much physical exertion as they were at sea level. Further, they may not feel well, and may have impaired mentation.

7.9.3.1 Acclimatization

Acclimatization is the process by which individuals gradually adjust to altitude hypoxia. It is an inadequately understood physiological process, involving a series of adjustments that occur over a period of hours to month. These changes all favor increased oxygen delivery to cells and efficiency of oxygen use.

The most important component of acclimatization is hyperventilation (increase in rate and depth of respiration). This begins to occur at altitudes of about 1500 m. The increased ventilation at altitude is driven primarily by the increased carotid chemoreceptor activity. With increased ventilation come hypocapnia and respiratory alkalosis, which limit further increased ventilation. The resulting hypocapnic alkalosis, which accompanies the increased ventilation, may be partially responsible for delaying the full increase in ventilation (i.e. ventilatory acclimatization), which can require a week or more to develop at moderately high altitudes. Hyperventilation raises alveolar oxygen tension and limits the fall in the PO_2 pressure gradient from the inspired air to the alveolus. The increased ventilation also increases the removal of carbon dioxide from the blood.

As acclimatization proceeds, there is gradual renal compensation by excretion of bicarbonate that tends to restore arterial pH to near-normal values. Heart rate (HR) increases with ascent, although, with acclimatization, resting heart rate approaches sea level values (except at extreme altitudes). At extreme altitudes resting and maximum HR converge as the limits of acclimatization are approached. Erythropoietin secretion in response to hypoxemia stimulates production of erythrocytes, resulting in increased hematocrit and hemoglobin concentrations.

The ability to acclimatize to altitude is quite individual: some people acclimatize rapidly; others require longer periods of time to acclimatize fully and are more prone to acute mountain sickness (AMS).

Successful acclimatization is characterized by the absence of altitude illness and improved sleep (Lyons et al., 1995).

Acclimatization in adults seems to be possible up to about 5000 to 5500 m. above this elevation there is a fine balance between the adjustment to altitude and deterioration as a result of chronic hypoxia. At more extreme altitude, deterioration becomes increasingly prominent, and above 8000 m, no acclimatization occurs.

The adjustments to hypoxia that begin immediately with acute hypoxic exposure, together with the continuing processes of acclimatization, collectively comprise the altitude adaptations. Altitude acclimatization can prevent altitude illness and improve performance, but the time and circumstances to achieve acclimatization may not always be available to units in a rapidly changing tactical situation.

7.9.4 EFFECT OF ALTITUDE ON PHYSICAL PERFORMANCE

The hypoxia associated with mountain (actual) or altitude (experimental) exposures reduces sustained physical performance capabilities to a degree directly proportional to the elevation, with the magnitude of the reduction associated with initial exposure usually greater than that associated with continued exposure.

The altitude limitations in total body oxygen transport begin to appear above 2000 m, where these respiratory limitations might be expected. Thus, the respiratory system imposes greater limitations on overall exercise performance at altitude than at sea level. Even if respiratory factors limit maximal oxygen uptake at high altitude more than circulatory factors, this does not mean the systemic oxygen transport and muscle energy metabolism adjustments that occur at high altitude do not affect physical performance.

After altitude acclimatization, systemic oxygen transport requirements during exercise at altitude can be satisfied with a lower cardiac output, and thus reduced cardiac work, than on arrival. In large part, this adaptation is enabled by the higher arterial blood oxygen saturation (SaO_2) resulting from ventilatory acclimatization, which, along with hemoconcentration due to high-altitude diuresis during the initial weeks at altitude and expanded erythrocyte volume after several months, raises CaO_2. The development of a glycogen-sparing adaptation further contributes to the improvement in exercise performance. Thus, in lowlanders ascending to high altitude, maximal performance appears to be limited by respiratory factors and submaximal performance by non-respiratory factors, but both respiratory and non-respiratory factors contribute importantly to performance improvements with acclimatization.

At sea level, circulation is the dominant factor limiting maximal exercise performance. Indeed, maximum oxygen uptake at sea level varies markedly among subjects, and that variability is closely linked to the variability in maximum cardiac output. However, this variability among subjects in their maximum oxygen uptake is markedly reduced as elevation is increased. Considering the limitation imposed on the number of oxygen molecules that can be ventilated at high altitude, and the limitation of lung diffusing capacity at altitude, one might conclude that the respiratory rather than circulatory system limits maximal oxygen uptake at high altitude. If oxygen does not reach the arterial blood, then increasing cardiac output might not greatly facilitate oxygen transport to the tissues. Wagner's analysis (1997) indicates that at the summit of Mount Everest, a doubling of maximal cardiac output will increase maximum oxygen uptake by less than 10%.

Altitude may affect the heart rate response to exercise. Maximal heart rate decreases after prolonged exposure to hypoxia. Cunningham and colleagues showed that plasma and urine catecholamine levels are elevated at high altitudes. At high altitude there is an increased parasympathetic tone at maximal exercise. This may be secondary to increased sympathetic tone and the baroreceptor reflex. Mean heart rate does not increase with the administration of supplemental oxygen, and so the impaired heart rate response is not attributable to hypoxia alone.

7.9.4.1 The Effects of Altitude on Maximal Aerobic Power

Maximal aerobic power can be affected by factors that alter any of the processes involved in oxygen transport or utilization. At altitude, a person is exposed to a progressive decrease in atmospheric pressure, with resultant declines in inspired, alveolar, and arterial oxygen pressures. As a consequence of the progressive hypoxia associated with increasing altitude, VO_2max declines at a rate inversely proportional to the elevation.

The minimal altitude at which a decrease in VO_2max has been detected and the rate at which it declines with increasing elevation Buskirk and colleagues suggested (1967) that there is minimal decrement in VO_2max until approximately 1524 m, with an average linear decline of 3.2% for every additional 305 m of altitude. In more recent years, VO_2max has been determined in subjects of varying fitness levels at lower and higher altitudes. Using information from some of these studies, Grover, Weil, and Reeves (1986) suggested that the decline in VO_2max begins at about 700 m, with a linear reduction of 8% for every additional 1000 m of altitude up to approximately 6300 m. Gore and colleagues reported (1996) that at 580 m, VO_2max declines 3.6% in fit, untrained individuals and 7% in elite athletes for every additional 1000 m. These and other data suggest that small declines in VO_2max begin at a much lower altitude than had been previously assumed by Buskirk and colleagues, and by Grover, Weil, and Reeves. In addition, it would appear that there is a more rapid, non-linear decline in VO_2max at altitudes in excess of approximately 6300 m. This more rapid decline may be linked with reduced blood flow, reduction of muscle mass, or metabolic deterioration, conditions that in any combination are often associated with chronic hypoxic exposure.

Potential sources of variation of the mean percentage of decline in VO_2max in competition at altitude includes subjects' fitness levels, and residence at altitude prior to a study; subjects' gender, changes in conditioning level resulting from increased activity during the exposure; subjects' smoking status, motivation, age, hypoxic ventilatory response; altitude sickness (AMS, high-altitude pulmonary edema, and high-altitude cerebral edema); rate of ascent to altitude, duration of exposure, timing of VO_2max measurements (e.g. pre-acclimatization and post-acclimatization); differences between training and exercise testing modes; use of inappropriate exercise mode (e.g. elite runners tested with bicycle ergometers); and altitude-induced muscle wasting.

7.9.4.2 Muscle Strength and Power

Muscle strength and maximal muscle power are generally not adversely affected by acute or chronic altitude exposure as long as muscle mass is maintained. In addition, alpha motor neuron excitability, nerve- and muscle conduction velocity, and neuromuscular transmission are not impaired, even at altitudes exceeding 4300 m. Unchanged maximal force and maximal power generation at altitude may relate to one or both of the following factors: maintenance of low resting levels of metabolites that, if higher (as during more-prolonged exercise), could potentially impair function of the contractile machinery; and preservation of normal resting levels of high-energy phosphates sufficient to support the rate of adenosine 5'-triphosphate turnover (1 – 2 $mmol \cdot s^{-1}$) for brief maximal muscle performance (Fulco, Cymerman, Muza, 1994).

It is obvious that military personnel are involved in many physical activities other than athletic events (e.g. running). Such activities are typically work- or mission-specific and can encompass extremely light to very demanding efforts that use different muscle groups for varying periods of time. In a sense, many work-related tasks have similarities to exercise performance in terms of effort intensity, volumes of active muscle involved, and activity duration.

With initial altitude exposure, arterial oxygen content is reduced. But for any specified submaximal exercise (exercise level when the individual reaches 85% or 90% of predicted maximal heart rate for age) or work intensity, oxygen transport to the working muscles is maintained because of a compensatory

increase in cardiac output. For maximal levels of exercise or work, maximal cardiac output cannot increase to levels greater than those at sea level, and thus cannot compensate for the reduced arterial oxygen content (CaO_2) (Young, et al., 1980). The result is a reduction in maximal oxygen transport and VO_2max. With sustained exposures of 2 to 3 weeks, CaO_2 increases toward sea-level values, owing to both hemoconcentration due to the loss of plasma volume and an increase in SaO_2. As a consequence of the decreased plasma volume, however, stroke volume and cardiac output are both reduced. During submaximal levels of exercise or work, the restored CaO_2 compensates for the reduced cardiac output such that oxygen transport to the working muscles is maintained (Burse, Cymerman and Young, 1987). But during maximal levels of exercise or work, the restored CaO_2 cannot compensate for the altitude-induced decline in maximal cardiac output, and maximal oxygen transport and VO_2max do not improve. Additionally, many other ventilatory, hematological, and metabolic adaptations may aid oxygen transport and improve exercise capabilities or military task performance.

7.9.5 HIGH ALTITUDE ILLNESSES

The term “high altitude illness” describes those medical conditions that are directly attributed to hypobaric hypoxia. Regardless the overlap between these symptoms, it is convenient to separate them into three types: acute mountain sickness (AMS), high-altitude cerebral edema (HACE) and high-altitude pulmonary edema (HAPE).

Rapid ascent to altitudes above 2500 m. often results in the syndrome known as AMS, which is the collection of symptoms (headache, nausea, vomiting, fatigue, anorexia, dizziness, sleep deprivation) that occur gradually, typically 6 to 12 hours after arrival at high altitude, and usually resolve within 1 to 3 days if further ascent does not occur. The most important risk factors for the development of AMS are sleeping altitude and rate of ascent. AMS is being increasingly recognized at altitudes of between 1500 and 2500 m. Descent to low altitude effectively and rapidly reverses AMS. It should be remembered that AMS represents the mild end of the spectrum of AMS. The major concern is that it may progress to life threatening high-altitude cerebral and/or pulmonary edema. A recent hypothesis of mechanisms of above-mentioned diseases is that hypoxemia elicits various neurohumoral and hemodynamic responses that ultimately lead to elevated cerebral blood flow, altered blood-brain barrier permeability, and cerebral edema. These changes result in brain swelling and elevated intracranial pressure.

High-Altitude Cerebral Edema is a rare but life-threatening form of altitude illness and has symptoms. Indeed, AMS and HACE probably represent two ends of a spectrum, the distinction between them being inherently blurred. It is likely to occur above 3500 m.

High-Altitude Pulmonary Edema usually occurs in the first 2 to 4 days after ascent to altitudes above 2500 m. As many as 10% of those ascending very rapidly to 4500 m will develop HAPE (Bärtsch et al., 1990), although incidences of 1 to 2% are more likely for standard ascent rates. HAPE is non-cardiac pulmonary edema, characterized by exaggerated pulmonary hypertension leading to capillary leakage through over-perfusion and/or stress failure. Inflammation may occur as a secondary event that results from alveolar flooding.

Low-altitude residents who spend prolonged periods (months) at very high altitude (above 5500 m.) may develop signs and symptoms of congestive heart failure. This condition has been referred to as **subacute mountain sickness**. It is characterized by right ventricular hypertrophy, pericardial effusion pulmonary hypertension, and resolution of symptoms and signs with descent.

Chronic mountain sickness is a disorder of long-term high-altitude residents and is characterized by high erythrocythemia and hypoxemia (Reeves and Weil, 2001). Signs and symptoms reflect profound polycythemia and hypoxemia: neuropsychological problems predominate, with headache, poor concentration, somnolence, dizziness, and poor exercise tolerance.

While ascending and residing at altitudes in some individuals several other disorders may occur as a result of influence of harsh environment: peripheral edema (Hackett and Rennie, 1979), high-altitude retinal hemorrhage, sleep and periodic breathing, neurological disorders (e.g. TIA), thrombosis, high-altitude anxiety and high-altitude cough, high-altitude deterioration and worsening of appetite. In addition, it is noted that infections are common at high altitude and are often slow to resolve (Murdoch, 1995; Durmovicz et al., 1997; Meehan, 1987).

7.9.5.1 Other Altitude-Related Injuries

While residing at terrestrial altitude, humans can get injuries related to other environmental factors: including cold, heat, UV radiation, and avalanche.

Hypothermia; the decrease of body temperature above 35°C, often occurs in individuals in the setting of inadequate clothing or shelter.

Frostbite; is more likely to occur in the presence of high winds, high altitude, contact with heat-conducting materials such as metal and water, dehydration, hypovolemia, tobacco use, or any other factors that reduce blood supply to the extremities.

Trench foot; is the result of prolonged exposure of the lower extremities to temperatures between 0 to 15°C without freezing of tissues. Injury is caused by decreased perfusion that lasts more than 1 to 2 days.

There is a possibility at altitude to suffer **heat exhaustion and heat stroke**, especially during exercise in the sun and hot weather, and when wearing improper clothing. Heat illness results from salt and water loss through sweating, inadequately replaced by oral intake.

At high altitude there is an increased risk of UV radiation from the sun forced by the thinner atmosphere to deflect and absorb the solar radiation and snow on the ground and hillsides that reflects the rays and increases the chance of burning, skin ageing, and neoplasia.

In snowy areas, the reflected sun can be very intense and can result in **snow blindness**, solar damage to the cornea and conjunctiva.

Risk of accidents and traumatic injuries while ascending, residing, and working in high altitude is markedly increased due to all mountainous environmental factors, and lack of mountaineering skills. For example, hypoxia leads to the impairment of mentation that causes decreased ability to concentrate while performing complicated activities (e.g. climbing, load carrying, skiing).

7.9.5.2 Prevention of Illnesses and Injuries on Mountains

An important aspect of preventive medicine on mountains involves ensuring that an individual has appropriate skills. All mission participants should be well trained, familiar with the use of a map and compass, and adequately dressed, equipped and proficient in base rope techniques and use of safety equipment. In remote settings rescue and evacuation plans should be made before they are needed. The mission participants should be selected according to the operational scenario, and ascending rate must be determined based on group members' capacities. In addition, the appropriate equipment (emergency kit, portable hypobaric chamber) can be also very helpful in urgent cases. If altitude illness symptoms occur, it is necessary to descend and/or take appropriate medications, if needed.

7.9.6 TRAINING STRATEGIES FOR IMPROVING PHYSICAL PERFORMANCE AT ALTITUDE

Mountaineering training is essential to fully appreciate the complexity of the problems encountered in mountain environments.

Because of hypoxia-induced physical performance decrements, military personnel rapidly transported from low to high terrestrial elevations should not be committed immediately to patrolling operations, entrenchment, combat, or other physically demanding duties, nor should they be expected to perform as well as they did at sea level (Levine et al., 1997).

Training modifications at altitude to increase the probability of successfully completing the tasks, compared with sea level, would include at least one of the following: an increase in task duration, a reduction in task intensity, or more-frequent rest breaks.

The specific amount and type of modification will depend on factors such as type of task involved, task difficulty, elevation, time at altitude, urgency, weather, terrain, and involved muscle mass (e.g. arm or leg work).

Acclimatization at altitude improves the oxygen-carrying capacity of the blood and aids exercise performance. It is nearly impossible to train at the same intensity as that engaged in at sea level when at altitudes above 2300 m. To improve performance at intermediate altitude, it is preferable to train at the same altitude, particularly for endurance events.

Two different regimens of altitude training have been proposed to improve performance: living at altitude and training at sea level or training at sea level and living at altitude. Living at altitude and training at sea level may offer the greatest physiological advantage for sea-level competition, since the physiological adaptation favor improved performance (Bailey and Davies, 1997).

During training at altitude, greater exercise intensity may not be desirable because of issues such as not being able to sustain a given task for a required duration. An altitude exercise training regimen should be successful in improving exercise performance more at altitude than at sea level. It would seem to be the net result of a complex interaction of conditioning level, training stimuli, deconditioning, altitude acclimatization, and level of hypoxia (Faulkner et al., 1967).

Why living at sea level and training at altitude may be more beneficial for improving exercise performance than both living and training at altitude is not well understood. Possible differences in success rates between these two experimental approaches do not seem to be related to differences in absolute exercise intensity, training altitude, training program duration, subject fitness levels, and peripheral muscle changes.

Living at altitude but training at a lower altitude ("living high and training low") theoretically allows both the advantageous changes of acclimatization to develop and the opportunity to train without reducing exercise intensity.

Levine and colleagues (1997) concluded that altitude acclimatization with sea-level training improves exercise performance at sea level. Because of these findings, Levine and Stray-Gundersen and Levine, Roach, and Houston hypothesized 1 year later that altitude acclimatization rather than hypoxic exercise per se was the key to altitude training because the natural form of "blood doping" (increased blood volume and hemoglobin) enhanced oxygen transport. In contrast, hypoxic exercise training has been reported to increase VO_2max without inducing changes in hemoglobin concentration or blood volume. Perhaps

hypoxic exercise training increases the "training effect," as evidenced by greater increase in aerobic enzyme activities and other peripheral changes.

7.9.7 SUMMARY

In ascending to altitude, an individual is exposed to a progressive decrease in atmospheric pressure that is associated with reductions in inspired, alveolar, and arterial oxygen pressures. As a consequence, VO_2max also declines. The minimal elevation at which a decrease in VO_2max is detectable is approximately 580 m. Fitness level, pre-exposure elevation, gender, and duration of exposure should be qualitatively assessed to determine their contribution to the overall variability. Because VO_2max declines, the relative exercise intensity is increased, therefore submaximal exercise performance is adversely affected. To maintain the same level of perceived difficulty at altitude for training or working on civilian or military tasks, the exercise or workloads must necessarily be reduced. Long-duration activities will be impaired more than shorter-duration activities at a given altitude. Muscle strength, maximal muscle power, and, likely, anaerobic performance are not affected at altitude as long as muscle mass is maintained. Physical performance may be improved at altitude compared with sea level in activities that have a minimal aerobic component and can be performed at high velocity (e.g. sprinting). Altitude acclimatization is associated with a multitude of ventilatory, hematological, and metabolic adaptations that have been thought to induce a beneficial effect on exercise performance. Training or living, or both, at altitude can improve altitude exercise performance in athletic events or military activities. Any potential benefit induced by altitude acclimatization for subsequent sea-level performance may be offset by the inability to maintain exercise intensity. Living at altitude but training at a lower altitude permits the theoretical advantage of both acclimatization and training, without reducing exercise intensity.

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Section 7.10 – EFFECTS OF CLOTHING ON OPERATIONAL PHYSICAL PERFORMANCE

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This section is intended to provide a brief overview of some of the means by which clothing can aid performance in operational environments, and some costs associated with use of clothing in those environments. There is not space to provide a complete treatise on military clothing. Not all types of military clothing are discussed, nor are specific military operations considered. This section does not specifically discuss footwear, respiratory masks, chemical defense ensembles or specific survival gear. The general principles discussed in this section do apply to these clothing items, and hopefully the reader will be able to extend the discussion provided below to those items.

We use clothing to protect us against the effects of the environment. In most instances, clothing provides a barrier between that environment and us that allows the creation of a comfortable microenvironment next to the body. From a performance point of view, wearing clothing is what often allows us to carry out work at all, especially as the environment becomes more extreme.

Clothing provides protection from thermal extremes, hot and cold, on land and in the water. Clothing allows us to survive the range of atmospheric pressures, from the extremely great pressures encountered in deep diving to the near-zero pressure of the vacuum of space. Our clothing helps us tolerate the increased gravitational acceleration encountered in flying high-performance aircraft. Clothing protects our bodies from mechanical trauma, ranging from cuts and scratches to the ballistic protection offered by body armor. Clothing also provides protection against threats posed by chemical, nuclear, and biological hazards.

By creating a barrier between the warfighter and the environment, clothing can interfere with the thermoregulatory process, particularly dry heat loss and the loss of heat through evaporation of sweat. Clothing can also interfere with performance because it provides added weight to be moved and may restrict freedom of movement.

7.10.1 PROTECTION

The properties of clothing that allow it to protect us from the environment include

1) Thermal protection;
2) Fluid permeability; and
3) Mechanical protection (Havenith and Heus, 2000).

7.10.1.1 Thermal Protection

Clothing offers protection against thermal insults through provision of insulation or by modifying the thermal reflectance or absorbance of radiant energy.

7.10.1.1.1 Insulation

Insulation is the resistance to heat transfer. In the United States, clothing insulation values are expressed in units of clo. One clo is the insulation provided by a typical 1940s business suit. One clo is equal to 0.155 $m^2 \bullet °C \bullet W^{-1}$, which implies a heat transfer limit of 6.45 watts per square meter of surface area per degree Celsius difference between the air and skin temperatures (Goldman, 1988b). One clo of insulation will maintain a sedentary person comfortably at 21°C, 50% relative humidity and no wind, indefinitely. In Europe, clothing insulation is often expressed in units of tog. One tog is equal to 0.645 clo or 0.1 $m^2 \bullet °C \bullet W^{-1}$.

The insulation provided by clothing is a function of the material used, its thickness, and the amount of air that is trapped in the weave of the fibers or between layers of clothing. In general, the thicker the cloth, the greater the insulation provided. Air is a good insulator, and the more of it that is trapped in the material of the clothing or between the layers of clothing, the greater the insulation provided by the clothing.

We need some degree of insulation when the environmental conditions fall below our comfort zone. The colder the environment the greater the amount of insulation needed.

We also need insulation when the environmental temperatures are much greater than is comfortable, such as in firefighting.

7.10.1.1.2 Reflectivity

Reflectance is the ability of clothing to reflect electromagnetic waves, including infrared (heat) and ultraviolet rays. By varying the reflectance of clothing, we can vary the ability to absorb the energy carried in such waves. By wearing white, reflective clothing, we decrease the amount of heat absorbed by our clothing and increase the ability to survive and work in hot climates. By wearing black, non-reflective clothing, we increase the amount of heat absorbed by the clothing and increase our ability to remain warm. An extreme example of use reflective clothing is the use of so-called “silver suits,” firefighting ensembles with shiny metallic coatings to reflect the intense heat of aircraft fires.

7.10.1.2 Permeability

Permeability refers to the ability to allow the transport of fluid substances through the clothing material. Usually the concern is the transport of water vapor, liquid water, or air through the layers of a garment because movement of these substances is important in maintaining thermal balance. In general, clothing represents a barrier to fluid exchange.

7.10.1.2.1 Water-Resistance

Garments can be designed to limit or prevent the penetration of water into the garment. Clothing that resists but still allows water penetration is categorized based on the pressure required to cause water to enter the material. A material is considered “water repellent” if it takes >0.5 psi to push water into the fabric. It is considered “waterproof” if it takes >25 psi, and “storm proof” if it requires >30 psi to force water into the fabric (Holmes et al., 1988). The degree of water protection needed varies with the use to which the garment will be put. Foul-weather gear to protect sailors on deck during storms needs to be storm proof. Survival suits designed to protect aircrew in the event of a water landing needs to be impermeable to water.

7.10.1.2.2 Water Vapor

Water vapor permeability is expressed as i_m, a permeability constant that takes on values from 0 (impermeable) to 1 (water vapor passes through freely).

Uniforms for use in hot climates should have a high water vapor permeability to allow sweat to evaporate from the skin and to provide cooling. Some garments are not completely permeable to water vapor but still can support cooling by evaporation of water. The clothing can be made of materials that can absorb the liquid from the skin and "wick" liquid water away from the skin and transport it to the clothing surface for evaporation. Such evaporation cools the garment rather the skin directly and is not very efficient at cooling the body. But the skin is left dry and the wearer feels more comfortable than if the skin were wet. Sports wear often has such wicking layers.

It is sometimes desirable to allow water vapor to exit a garment but also keep liquid water out. Examples are clothing to be worn while working outdoors in the rain or snow. A series of materials have been developed to meet these needs. These materials have pores that are too small to allow water droplets to move in through the fabric (waterproof), but large enough to allow water vapor to pass out of the garment. In this way, they provide protection against rain or snow, but allow the fabric to let water vapor out and allow body cooling during work. One might note that these fabrics are not impermeable to water. If you fall into a lake, the water pressure gradient will force water through the pores.

7.10.1.2.3 Air

The air permeability of a fabric determines its resistance to air penetration. Increased airflow through a garment aids in cooling the body. Garments such as windbreakers, that are designed to block the wind, have low air permeability. Clothing designed for use in hot weather is usually quite permeable to air flow to allow the air to assist with cooling. Using porous materials or adding vents to a garment can enhance air permeability.

Allowing a "loose fit" can also enhance airflow through a garment. As the garment wearer moves, the material of the garment will flex and fold, resulting in a "pumping" action that promotes some air movement within the garment.

7.10.1.3 Mechanical Barrier

Clothing offers a wide range of mechanical protection. The outer fabric protects the skin against chaffing, scuffs, cuts, abrasion, or other trauma that might result from equipment carried, contacting objects, or diving to the ground.

A greater level of mechanical barrier protection in military clothing is offered by body amour, which offers protection against shell and grenade fragments and even bullets. Body armor consists of several layers of woven fabric made of para-aramide fibers (e.g. Kevlar, Twaron, or Technora) or high-tenacity polyethylene fibers (e.g. Dyneema or Spectra), augmented with hard ceramic plates. When a bullet or projectile strikes body amour, it is caught in a "web" of high performance fibers that absorb and disperse the impact energy that is transmitted to the vest from the bullet, causing the bullet to deform or "mushroom." Hard body armor works by disrupting the aerodynamic shape of the bullet and dissipating the energy by shattering the ceramic top layer.

Body armor offers three different levels of protection:

1) Spall protective (fragments from amour),
2) Shell fragment protective, and
3) Bullets protective (van de Linde and Lotens, 1988).

Levels 1 and 2 can be met using the soft body armor, but the bullet-protective level would require such a large number of aramide panels that the additional protection of the ceramic plates is needed.

It is important to have the appropriate level of protection. If the protection provided is less than that required, the projectile may deform without completely dissipating its energy. This deformed fragment may cause more damage as it passes into or through the body than would an undeformed fragment. Less protection than necessary could conceivably be worse than no protection.

7.10.2 PERFORMANCE DECREMENTS

As noted above, the protection offered by clothing can come with a performance cost. Clothing can interfere with the body's ability to exchange heat with the environment, and wearing clothing can increase metabolic demands because of the weight of the clothing and the freedom of movement restriction imposed by clothing.

7.10.2.1 Heat Exchange Disruption

As discussed in Section 7.1.1, the body gains or loses heat through radiation, conduction, convection, and evaporation. Clothing poses a physical barrier to all these methods of heat exchange. Exchange of heat by radiation is greatly reduced by most clothing ensembles. The insulation provided by clothing decreases the possibility of heat exchange by conduction, heat exchange by convection is limited by the air permeability of the garment, and heat exchange by evaporation of sweat is limited by the water and water-vapor permeabilities of the clothing. These effects are most often positive ones, because clothing is worn to maintain a comfortable level.

The amount of insulation must be varied to match both the environment and the physical work demands. If one is engaged in physical work, the clothing must allow the excess metabolic heat produced to escape to the environment to prevent the body from overheating. If one is sedentary, the clothing must provide sufficient insulation to prevent the loss of heat from the body. Dressing for work in the cold can be particularly challenging. One must dress warmly enough to avoid becoming chilled when resting, but the clothing must allow for sufficient heat loss when working (e.g. marching with a load). One of the dangers is that if one works hard enough to cause sweating, the presence of water in the clothing decreases the insulation value of the clothing and leads to more-rapid cooling when one stops working (Richards et al., 2005). To combat this problem one should wear removable layers of clothing, or clothing that can be easily opened up to allow heat to escape when preparing for work in the cold. By these means, the insulative value of the clothing can be varied to meet situational demands.

Water and water vapor permeabilities determine the rate and route by which perspiration can be removed from the surface of the body. If the water vapor permeability of the garment is large enough, water can evaporate from the skin and the vapor can move out through the garment. In this instance, the skin is cooled directly. If the water vapor permeability is not so large, the water vapor will condense in the clothing. If the water permeability of the clothing is sufficiently great, the water will move to the outer surface of the garment and evaporate there (conditions permitting). In this instance, cooling takes place at the surface of the garment. Body cooling is achieved, in part, by contact with the cooled clothing material, rather than by evaporation. Heat exchange in this way is not as effective as when garments have high vapor permeabilities.

When a garment is impermeable to water vapor, liquid water can build up inside the garment. Because the vapor does not leave the garment to evaporate, this avenue of heat loss is cut off. This is the situation that pertains when one wears chemical defence clothing. These garments have a rather large insulative value ($\approx$ 2 clo; (Goldman, 1988b)) so heat transfer is impeded. Additionally, such garments have relatively low permeability ($i_m \approx 0.3$; (Goldman, 1988b)). Water vapor from sweating cannot evaporate. As a result, heat builds up inside the garments when working and cannot be dissipated. This heat build-up severely limits the ability to work while wearing these garments unless an external method of cooling is available

(e.g. ice vests, plunging hands in cold water, or an external source of moving air blown inside the suit.). A similar situation occurs when wearing body armor, which is impermeable to water vapor (van de Linde and Lotens, 1988).

7.10.2.2 Weight

Another limitation imposed by working in garments with heavy insulation or mechanical barriers (e.g. body armor) is that the weight of the garment is increased, adding to the physical workload associated with motion. The metabolic cost of walking or running is proportional to the weight being moved, and the weight of the clothing contributes to this cost. The metabolic cost of walking 3 mph is approximately 12 ml O_2•kg^{-1}•min^{-1}. At this speed, every kilogram of clothing adds about 12 ml O_2•min^{-1}. If a set of upper-body torso body armor weighs 4.5 kg (Danielsson and Bergh, 2005; Lotens, 1988; van der Linde and Lotens, 1988) the additional cost of walking at 5 km h^{-1} would be 0.54 l O_2•min^{-1}. The impact of such an increase varies with body size and fitness. The load will represent a smaller proportion of carrying capacity for larger and more-fit individuals.

7.10.2.3 Mobility Costs

However, there is an additional metabolic cost associated with the restriction of movement caused by bulky, stiff or multilayer clothing ensembles. Lotens reviewed the effects of mobility costs in 1988. He reports that the energy cost of movement goes up linearly with the number of layers of clothing (an indicator of bulkiness) when the garments were adjusted to be equal in weight. A 6 to 7 layer suit has an 18% greater energy expenditure when walking at 5.6 km h^{-1} than a garment with 1 – 2 layers (Teitlebaum and Goldman, 1972; cited in Lotens, 1988). Dorman and Havenith (2005) also studied this effect and found additional metabolic costs range from 5 to 20% above the cost of walking on a treadmill at 5 km h^{-1} in trainers and a track suit, after controlling for the weight of the protective gear compared with this control condition. Some values of interest are army fatigues + body armor, 109% of control metabolic cost, Army fatigues + NBC ensemble, 117%. Clearly, decreasing the mobility costs associated with clothing ensembles is a necessary research and development goal.

7.10.3 CURRENT TRENDS

Development of clothing materials and clothing items continues to be an active area of research. The aims of this research are, in part, to continue to address the problems outlined in this section: improved protection against the operational environment and specific battlefield threats, maintenance of thermal comfort in extreme conditions, and reduction in weight and bulk, with the overall goal of providing protection to the warfighter while maintaining his or her full combat effectiveness. Specific threat areas being addressed include ballistic protection, surface heat and blast, detection identification (camouflage, and concealment against a variety of threats), biological and chemical protection, nuclear and radiological protection, directed-energy weapons, and mobility and load carriage (Scott, 2000). Approaches include the development of smart/reactive materials that change their properties in response to changing conditions. New clothing systems that utilize nanotechnologies as sensors to detect environmental conditions, as power supplies to support protective systems, and as mechanical activators of material properties changes are being considered. These new systems will be needed to counter the threats of tomorrow's battlefield.

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Section 7.11 – EFFECTS OF EXTENDED OPERATIONS ON PHYSICAL PERFORMANCE

by

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7.11.1 BACKGROUND

The increasingly fast-paced deployments to operational theatres and advances in technology, such as night-vision capabilities, have pushed the boundaries of modern warfare. The "24-hour battlefield" is a common reality among militaries around the globe. As a consequence, today's soldiers rapidly deploy across time zones all over the world and are expected to have the stamina to fight for longer periods of time without rest or sleep. Continuous operations (CONOPS) are defined by a period of continuous land combat with opportunity for sleep, although this sleep may be brief or fragmented. Sustained operations (SUSOPS) are defined as continuous land combat with no opportunity for sleep. By definition, CONOPS will likely involve periods of SUSOPS. Extended operations will potentially have negative effects on soldiers' physical performance because they will most likely be engaged in prolonged physical work, possibly be underfed, and be subject to sometimes difficult environmental conditions during those operations. The impact of negative caloric intake and environmental conditions were already covered in this chapter, therefore it will not be discussed further. Factors that will be examined in greater detail are sleep deprivation and trans-meridian travel.

7.11.2 SLEEP DEPRIVATION

When adults get considerably less than 7 hours of sleep per 24-hour period, they begin to feel the effects of sleep loss (Armstrong, 2000). Sleep deprivation can de described as a lack of sleep ranging from a couple of hours to many days. Partial sleep deprivation is when an individual regularly gets less than 5 hours of sleep per night, short-term sleep deprivation is defined as less than 45 hours of wakefulness, and long-term sleep deprivation is when someone is kept awake for a period of time greater than 45 hours (Pilcher and Huffcutt, 1996). Sleep deprivation is predominantly detrimental to cognitive functions and decision making. For every 24-hour period without proper recovery sleep, individuals will experience a 25% decrease in cognitive performance, making them virtually militarily inefficient after only a few days of SUSOPS (Haslam, 1984). Individuals suffering from sleep loss will have great difficulty concentrating, even on simple tasks; they will lose much of their creative thinking, and they will feel more confused and fatigued than if they were properly rested. They will also tend to pay less attention to self-care, such as eating, hydrating, staying dry and clean, thereby exposing themselves to other potential problems. Moreover, mood and motivation are greatly affected by sleep deprivation and can eventually play a predominant role in physical performance. The effects of sleep deprivation have a dose-response relationship with cognitive functions and appear to be exacerbated by the circadian trough (0300 – 0600 hrs). Although the literature is clear on the negative impacts of sleep loss, some studies have reported that incentives such as promised sleep or warm shelter could maintain or even improve mental performances (Haslam, 1983).

7.11.3 EFFECTS OF SLEEP DEPRIVATION ON PHYSICAL PERFORMANCE

7.11.3.1 Cardiorespiratory Function

Studies examining the effects of sleep loss on physical performance range anywhere from between 24 and 84 hours of wakefulness (Armstrong, 2000; Castellani et al., 2003). Although some report minor effects of sleep deprivation on physical performance, surprisingly most of them have found very little physiological changes in cardiorespiratory functions in partially or totally sleep-deprived subjects. Even in severely sleep deprived individuals, VO_2, VCO_2, minute ventilation, blood pressure, and heart rate did not differ from non-sleep-deprived control measures (Martin and Chen, 1984; Martin and Gaddis, 1981; Symons et al., 1988). Blood lactate levels and respiratory quotient for varying intensities remained unchanged, suggesting that sleep deprivation does not cause any major fuel-selection shifts during exercise (Martin and Chen, 1984; Symons et al., 1988). A study involving only female subjects demonstrated that women's response to exercise after sleep loss is identical to men's (Goodman et al., 1989). Hence, sleep deprivation resulting from SUSOPS is not detrimental to the aerobic or the anaerobic capacity of the soldiers.

7.11.3.2 Muscular Function

Similar to the cardio-respiratory function, muscular function is not affected by sleep deprivation. After 30 to 72 hours of sleep loss, subjects did not display any changes in maximal isometric or isokinetic strength (Symons et al., 1988) or electromechanical responses to exercise (Van Helder and Radomski, 1989). Physical performance can be expected to decrease during SUSOPS, not by lack of sleep but simply because the same muscle groups tend to be overutilized over a long period of time without adequate recovery (VanHelder and Radomski, 1989).

7.11.3.3 Thermoregulation

A soldier's ability to tolerate heat or cold will certainly affect his or her effectiveness in the field. As mentioned earlier, SUSOPS often involve multiple stressors, including sleep deprivation, negative energy balance, and physical exertion. Sleep deprivation has been shown to have a detrimental effect on the body's capability to properly maintain core temperature. Studies have found that prolonged sleep loss reduces dry heat loss, sweat rate, and sweat sensitivity, meaning that the onset of evaporative heat loss comes at a higher temperature (Kolka et al., 1988; Sawka et al., 1984). These changes result in higher risk of heat stroke when sleep loss is combined with moderate or extreme exercise (Armstrong, 2000). Obviously, considering that soldiers already carry equipment that impairs their thermoregulatory mechanisms, sleep loss will most likely result in a decrease in physical performance when exposed to extreme temperatures. On the other hand, the effect of sleep deprivation on cold-exposure tolerance is not as clearly defined. In a study of 84 hours of SUSOPS, researchers found that the thermoregulatory response may be altered by sleep loss. In that particular experiment, sleep deprivation induced greater decline in core temperature among the subjects compared with controls due to either a delay in the shivering response or by heat redistribution caused by insulative acclimation (Castellani et al., 2003).

7.11.3.4 Perceived Exertion

Contrary to the physiological data, the subjective measures of performance, such as perceived effort, breathing, pain, and fatigue, seem to be more significantly affected by lack of sleep. Many studies have reported higher ratings of perceived exertion (RPE) for submaximal and maximal intensity exercise. For the same heart rate or work rate, sleep-deprived subjects perceive to be working and breathing harder and feel more fatigued (Rodgers et al., 1995; Martin and Gaddis, 1981; Symons et al., 1988; Armstrong, 2000). These higher ratings of perceived exertion are undoubtedly linked with the greatest effects of sleep loss on physical performance, which is the exercise time to exhaustion. In studies involving more than 48 hours of sleep deprivation, researchers reported decreases of up to 20% in exercise time to exhaustion

despite any changes in physiological parameters (VanHelder and Radomski, 1989; Symons et al., 1988; Martin and Chen, 1984; Rodgers et al., 1995).

7.11.3.5 Motivation

During SUSOPS, soldiers may have the physiological capability to perform physically demanding tasks over prolonged periods of time, but their attitude and motivation to carry out those tasks will be severely challenged by sleep loss. Mood is most severely affected by sleep deprivation as are most other psychological and cognitive functions, and it will be the leading indicator of physical performance (Nindl et al., 2002). Decreased mood state will result in a decrease in physical performance and on the willingness of individuals to push their bodies to exertion (Belenky et al., 1987; Pilcher and Huffcutt, 1996; Symons et al., 1988). The nature of the task also plays a role in motivation to perform physically. Boring and repetitive or continuous tasks at low intensity (35 – 40% VO_2) will be more subject to a decrease in performance (Rodgers et al., 1995). Soldiers' attitudes will dictate their level of physical performance; therefore, a positive change in attitude may override the pure effects of sleep deprivation (Haslam, 1983). In military operations, leadership plays a critical role in the overall performance of soldiers. Well-led troops can perform for longer periods of time while maintaining their work output (Belenky et al., 1987). Soldiers who believe in their leaders will tend to feel less fatigued and be able to tolerate higher intensities than soldiers who have little faith in their leadership. Consequently, leadership styles during SUSOPS become a critical factor in the success or failure of a potentially physically demanding mission.

7.11.4 COUNTERMEASURES TO SLEEP DEPRIVATION DURING SUSOPS

Finding solutions to counter the effects of sleep deprivation during CONOPS is simpler than applying them during SUSOPS where the schedule, environmental conditions, and the stress level are completely uncontrollable. In CONOPS that don not necessarily involve combat, using well-established shift-work schedules will help maintain cognitive and physical performance at acceptable levels for weeks at a time. Shift work should be set according to the level of cognitive demands: longer shifts for tasks that require limited cognitive demands, and shorter for ones that are more complex (Belenky, 1997). As for SUSOPS, it is almost impossible to apply the concept of shifts. So military planners and leaders need to use other solutions in order to ensure proper vigilance, psychological, and physical performance of their troops.

7.11.4.1 Naps

Naps can sometimes be perceived negatively in a military environment but they can certainly be very beneficial to soldiers. Thus leaders should be well aware of this perception and address it in SUSOPS situations. The recuperative value of sleep depends on the duration and the timing of that sleep. A prophylactic nap of 2 to 4 hours can be as effective as 1.5 – 3 cups of coffee and can help maintain alertness and cognitive performance near baseline level over a 24-hour period (Armstrong, 2000). Although naps can be valuable, they can also be detrimental. Brief or fragmented sleep has little or no recuperative value and can be as debilitating as total sleep deprivation (Belenky, 1997). Furthermore, individuals choosing to take naps might suffer from a period of sleep inertia upon wakening. Sleep inertia can range from 15 to 30 minutes and can make the individual feel groggy or sluggish. Sleep inertia is amplified by both the depth of sleep of the individual and its timing in the circadian rhythm. This condition can potentially contribute to decrease in military performance.

7.11.4.2 Medication

There may be some situations where soldiers will be required to go to sleep in preparation for certain missions. That sleep opportunity may not necessarily come at the right time of day. In those instances,

hypnotics such as Temazepam, Zaleplon, and Zolpidem may be used as a viable solution to promote sleep. These medications are either sleep maintenance or short-duration sleep agents. Caution should be used when utilizing such medications since they are not recommended when individuals are "on-call" or can be sent on a mission on a moment's notice, because they exacerbate sleep inertia and may result in decreased performance and vigilance (Caldwell and Caldwell, 2005). In the opposite situation, when soldiers are required to be alert for prolonged periods of time, the use of stimulants may be valuable. The most common stimulant is caffeine and is readily available in military rations. Besides helping prevent sleepiness, caffeine has a positive dose-response effect on cognitive performance, reaction times, and mood (Lieberman et al., 2002; Caldwell and Caldwell, 2005). The fact that caffeine is widely used by many may diminish its stimulant effect on certain severely fatigued individuals who are accustomed to large caffeine doses (Caldwell and Caldwell, 2005). Unfortunately, caffeine does induce some side effects, such as increased heart rate, blood pressure, nervousness, anxiety, restlessness, and reduced fine-motor skills. Additionally, caffeine is a diuretic will increase frequency of urination and potentially increase the risk of dehydration (Caldwell and Caldwell, 2005). However, its positive performance enhancement may overrule these side effects and in fact support its use in critical situations.

The use of amphetamines has also been reported in military operations. Amphetamines are much more efficacious than caffeine on promoting alertness and maintaining cognitive functions but need to be prescribed under medical supervision, which can be problematic in the field. They also lead to more-serious medical conditions, such as palpitations, increased blood pressure, tachycardia, restlessness, and euphoria (Caldwell and Caldwell, 2005). Although amphetamines can be addictive, the length of SUSOPS is not likely to cause such dependence. In the last decade, a drug used in the treatment of narcolepsy has been used by soldiers to enhance alertness during SUSOPS. Modafinil is a stimulant that provides the same positive effects as amphetamines but without most of the side effects. Modafinil presents no risk of dependence and does not affect recovery sleep (Caldwell and Caldwell, 2005). Soldiers can to nap or sleep if they have the opportunity, even if they are still under the effects of the drug. Considering its positive effects and potential undesired side effects, Modafinil seems to be a drug of choice for SUSOPS (Caldwell and Caldwell, 2005).

Regardless of their effects, drugs will never be a substitute to sleep to prevent long term consequences of sleep deprivation on cognitive or physical performances. Regularly scheduled recovery sleep is an absolute necessity for any soldier. Medication such as stimulants can only help sustain alertness for so long before the soldier becomes less battle efficient.

7.11.5 TRANS-MERIDIAN TRAVEL OR "JET LAG"

Rapid movement of troops across multiple time zones will cause shifts in a soldier's internal clock or circadian rhythm. These shifts will cause a desynchronization of the circadian rhythm, which will take time to readjust to the new local environment. During this adjustment period, several physical performance capabilities may be decreased; therefore, some attention should be given to the type of work or missions that soldiers carry out upon arriving in a new theatre of operation. Some of the psychological effects of what is commonly called "jet lag" include sleep disorders, difficulty concentrating, irritability, and distorted estimation of time, space, and distances. Physically, individual may feel light-headed, and experience loss of appetite and gastrointestinal disturbances (Manfredini et al., 1998). The direction of flight is reported to also affect the magnitude of symptoms. Westward flights, which are characterized by a delay in circadian rhythm, generally take less time to adapt or resynchronize than eastward flights, which are characterized by an advance in the body's biological clock. The mean re-entrainment time for westward travel shift rate is 92 minutes/day whereas it is 57 minutes/day for eastward flights (Caldwell and Caldwell, 2005).

7.11.5.1 Effects of Jet Lag on Physical Performance

All physiological systems have a certain cycle that follows the body's circadian rhythm. A desynchronization in the rhythm will disrupt many functions in any given individual. Body temperature, heart rate, blood pressure, gastrointestinal and urinary functions, and ventilation may all be adversely affected by traveling across time zones (Armstrong, 2000; Caldwell and Caldwell, 2005). In turn, optimal physical performance is dependent on most of these systems, so a desynchronization in circadian rhythm is bound to have an impact on one's ability to produce best performances upon arriving in a new environment. Arm strength, sprint times, hand-eye coordination, performances on lifting and carrying tasks, which are all essential to soldiers involved in SUSOPS or combat situations have been reported taking anywhere from 1 to 5 days to reach baseline levels (Armstrong, 2000). Consequently, any air travel involving more than 5 time zones should be planned carefully in advance and countermeasures should be used to ensure that troops are not put in a physically disadvantageous situation.

7.11.5.2 Measures to Prevent or Reduce Jet Lag

The simplest way to try reduce effects of jet lag is to modify sleep patterns to the destination schedule several days in advance, taking in consideration the direction of travel when delaying or advancing sleep times. Unfortunately, this may be very difficult to achieve when troops are deployed rapidly or the schedule pre-travel is out of their control (Manfredini et al., 1998). Ideally, soldiers should have a few days to adapt to the local environment before being tasked on critical missions. During the first few days, individuals should quickly follow the local time cues for their sleep and mealtimes and try to avoid taking long naps. Exposure to bright light and no light at appropriate times is a key concept for rapid adjustment of the circadian rhythm and can be done by having rooms with windows or access to outdoor cues (Waterhouse et al., 2004). Moreover, mild exercise during the early days can help the body's internal clock readjust faster. On the other hand, very-intense exercise may have detrimental effects since it may cause disturbed sleep (Armstrong, 2000).

Although clear scientific relationships have not yet been demonstrated, the composition and timing of meals can help improve adjustment times of trans-meridian travel. Meals high in carbohydrates and low in proteins will help tryptophan uptake, an amino acid that converts to serotonin, by increasing drowsiness. Similarly, meals high in proteins and low in carbohydrates will improve tyrosine uptake and its conversion to adrenaline, thus augmenting arousal level (Manfredini et al., 1998). Timing those meals with their desired effects according to the local schedule has led to positive results on sleep disturbances and subjective feelings of fatigue in military personnel compared with controls (Manfredini et al., 1998). In addition to nutrition, the use of caffeine at appropriate times to enhance alertness will help shift the sleep wake cycle (Armstrong, 2000). The use of chronobiotic drugs that affect biological time structure can also be helpful (Waterhouse et al., 2004). Melatonin, a pineal hormone normally secreted at night, can be administered orally to promote sleepiness. Similar to meal composition, administration of melatonin should obviously follow the direction of travel so morning administration delays the circadian rhythm and evening administration advances it (Manfredini et al., 1998).

In summary, measures to prevent negative effects of jet lag have not all been scientifically validated and may vary from one individual to another. So the safest approach in military operations is to allow for a few days of local "acclimation" before initiating any meaningful operations with new arriving troops.

7.11.6 SUMMARY

Continuous and sustained operations have a direct impact on the soldiers' overall performance capabilities and thus, should be planned and led with the appropriate information and strategies to minimize the adverse effect of such operations on the human body. Included in those strategies are some that would not

be desired in normal conditions, such as certain types of medication, but given the circumstances surrounding what the soldiers need to accomplish, would certainly be warranted.

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