DEFENCE PHYSICAL EMPLOYMENT STANDARDS PROJECT

Infantry and Airfield Defence Guards

REPORT 13

CAPACITY OF WOMEN TO IMPROVE PHYSICAL PERFORMANCE: A REVIEW

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CONDUCT OF A PHYSICAL EMPLOYMENT STANDARDS STUDY FOR THE AUSTRALIAN DEFENCE FORCE

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COMPLETED AND PLANNED REPORTS

No.	Short Title[1]	Date[1]	Type
	Completed Reports		
1	Selection of Key Trade Tasks for Detailed Observation	Mar 04	Minor
2	Selection of Potential Endurance Tests & Anthropometric Measures	Sep 04	Minor
3	Review of Injury Data: Infantry and ADG	Feb 05	Minor
4	Trade Tasks Movement Analysis: Infantry and ADG	Apr 05	Minor
5	Trade Tasks Risk Analysis and Risk Mitigation: Infantry and ADG	Jul 06	Minor
6	The Effect of Physically Demanding Infantry and ADG Trade Tasks on Cognitive Performance: a Pilot Observational Study	Apr 05	Minor
7	Retrospective Surveys of Injuries (2004 & 2005): Infantry and ADG	Sep 06	Minor
8	Selection of Criterion Trade Tasks: Infantry and ADG	Mar 05	Minor
9	Trade Task Analysis: Infantry and ADG	Sep 06	Major
10	Reliability of Potential Physical Employment Tests: Infantry and ADG	Nov 05	Minor
11	Normative Physical Performance Data: Infantry and ADG	Sep 06	Major
13	Capacity of Women to Improve Physical Performance: a Review	Sep 06	Minor
	Planned Reports		
12	Physical Performance Standards: Infantry and ADG	Oct 06	Major

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ABBREVIATIONS AND ACRONYMS

ACSM	American College of Sports Medicine
ADF	Australian Defence Force
APFT	Army Physical Fitness Test
BCT	Basic Combat Training
C+E	Caffeine/Ephedrine
CATT	Combat Arms Trade Task
CHO	Carbohydrate
CI	Confidence interval
CMS(R)	Common Military Syllabus (Recruits)
DEXA	Dual Energy X-ray Absorptiometry
DPESP	Defence Physical Employment Standards Project
IET	Initial Employment Training
MAOD	Maximal Accumulated Oxygen Deficit
MMH	Manual-material Handling
OR	Odds ratio
PCr	Phosphocreatine
PRT	Physical Readiness Training
PT	Physical Training
RR	Relative risk
STINET	Scientific & Technical Information Network
SD	Standard Deviation
WRAC	Women's Royal Army Corps

GLOSSARY

Absolute aerobic power	Maximal oxygen uptake (aerobic power) expressed as litres of oxygen consumed by the body per minute.
Anaerobic capacity	The maximum amount of energy that can be supplied by the anaerobic energy system.
Anaerobic power	The rate of supply of energy from the anaerobic energy system.
Aerobic power	See maximal oxygen uptake.
Ballistic	A movement in which a part of the body is quickly moved against the resistance of agonist muscles or against the limits of the joint.
Concentric	Muscle action in which the muscle is shortened under its own power.
Eccentric	Muscle action in which the muscle resists while it is forced to lengthen.
Exercise economy	The rate of energy expenditure as a function of velocity of movement.
Hypertrophy training	Training focused upon the enlargement of a muscle by the increase in size of cells.
Lactate threshold	The maximal exercise intensity at which steady-state exercise can be maintained.
Maximal oxygen uptake ($\dot{V}O_{2max}$)	The maximal capacity for oxygen consumption by the body during maximal exertion; also known as aerobic power, aerobic capacity, maximal oxygen consumption and cardiorespiratory endurance.
Muscle hypertrophy	An enlargement of a muscle by the increase in the size of the muscle cells.
Muscular endurance	The ability of the muscle to continue to perform without fatigue.
Neural adaptation	An adaptation to strength training that results in changes within the nervous system that allow a trainee to more fully activate prime movers in specific movements and to better coordinate the activation of all relevant muscles, thereby effecting a greater net force in the intended direction of movement.
Plyometric training	Training that involves powerful muscular contractions in response to a rapid stretching of the involved musculature. Sometimes referred to explosive-reactive power training.
Power	A skill-related component of physical fitness that relates to the rate at which one can perform work.
Power training	Training focused upon developing the capacity of an individual to perform powerful movements. That is to lift heavy weights as quickly as possible.
Relative aerobic power	Maximal oxygen uptake (aerobic power) expressed relative to body weight. Expressed as millilitres of oxygen consumed per kilogram of body weight per minute.
Relative intensity	An exercise intensity expressed relative to the maximal capacity of an individual.
Repetition maximum (RM)	The amount of weight that an individual can lift a given number of times (repetitions).
Strength	The ability of a muscle to exert a force.
Strength endurance training	Training focused upon the development of the ability of a muscle to apply a sub-maximal force repeatedly or to sustain a muscular contraction for a certain period of time.
Workload	The amount of work that an individual is required to perform. Usually expressed in units of Watts.

1 INTRODUCTION

1.1 Background to the Defence Physical Employment Standards Project

1.1.1 Military operational tasks are physically demanding and incur the risk of injury. In order to address the issues and costs associated with the high injury rates and focus on ways to reduce the risk of injury to Australian Defence Force (ADF) personnel, the ADF Chiefs of Service Committee (COSC) has endorsed a number of injury prevention strategies aimed at examining, analysing and evaluating injury-related risks and hazards within the ADF. In line with those strategies, COSC has affirmed that ADF employment policy is to be competency based and agreed that physical employment standards should be developed for combat arms trades. The purpose of the Defence Physical Employment Standards Project (DPESP) is to develop these performance-based competency standards.

1.1.2 The ADF has employed the services of the University of Ballarat (UB) to undertake the DPESP. This involves reviewing combat arms trade tasks (CATTs), establishing a set of criterion CATTs, developing a battery of simulation and predictive tests based on the criterion CATTs to be used to assess the physical competency of ADF combat personnel, and making recommendations for associated physical employment standards (See Reference Documents A and B).

1.1.3 In the initial phase, the study is focused on one Army corps - Infantry, and one Air Force mustering - Airfield Defence Guards (ADG).

1.1.4 The steps in the DPESP study are:

a. identification and observation of CATTs;

b. analysis of physical demands and cognitive effects of CATTs;

c. identification and analysis of injury risks of CATTs;

d. identification of criterion CATTs on which to base tests of physical performance;

e. development of a set of potential physical employment tests (PETs), and establishment of their reliability and validity;

f. collection of normative data on the PETs;

g. selection of the final battery of PETs and determination of minimum performance standards on each.

1.2 Background to this Review

1.2.1 Women are deployed within a range of physically and psychologically demanding roles within the Australian Defence Force (ADF). These include combat roles within the Navy and Air Force and combat support roles within the Army. In recent times there has been considerable debate within the Army about the capacity of women to undertake even more physically demanding roles, including participation in the combat arms trades.

1.2.2 A brief examination of information pertaining to the defence forces of other nations reveals that although more than a dozen nations permit women to undertake combat roles, most do not permit women to undertake combat roles within their armies (Goldstein, 2001). The decision to not admit women to army combat roles reflects a range of historic, cultural and physical factors. In general, the physical factors are focused upon the capacity of women to undertake the physically demanding roles to a level that equals the minimum standard for males. There is no doubt that the physical demands of some combat arms trade tasks (CATTs) are high (Report Number 4 in this series, Reference Document C). However, given the high acute and chronic injury rates experienced by male soldiers and airmen undertaking these physically demanding tasks (Report Number 7 in this series, Reference Document D), it is problematic whether the capacity of women to complete these tasks should be set as a barrier, or whether the high-risk and most physically demanding tasks should be modified in ways that do not impair deployment capacity, but reduce their inherent injury risk. Such modifications may remove or lower barriers that at present affect the capacity of women to be engaged in army combat roles.

1.2.3 Notwithstanding the nexus between injury risk and physical barriers noted above, an analysis of the physical demands of the CATTs contained with the Rifleman and Airfield Defence Guard trades reveals that these trades require soldiers/airmen to possess high levels of cardiovascular endurance, strength, muscular endurance and power (Reference Document C). These trades appear to have a lesser requirement for high levels of speed and anaerobic capacity. Given the physical capacities required by the Rifleman and Airfield Defence Guard trades, the question arises as to whether suitably trained women would be capable of meeting the minimal physical requirements of these trades. This question raises a conundrum in the context of the Australian Army; since no women have participated in the Initial Employment Training (IET) for these trades, there is no empirical evidence of whether or not women can be trained to meet the minimal physical requirements of these trades. An alternative way of providing some evidence to answer the question is to undertake a comprehensive examination of the information available in the military and civilian literature regarding the capacity of women to enhance their physical performance in the key physical capacity areas of cardiovascular endurance, strength, muscular endurance and power. It is possible that such information may be able to provide some evidence and insight, albeit theoretical, as to whether appropriately trained women would be able to meet the minimal physical employment standards for entry into the Rifleman and Airfield Defence Guards trades within the Australian Army and Air Force, respectively.

1.2.4 Therefore the purpose of this review is to provide advice to the ADF on the capacity of women to improve their physical performance capacity through participation in physical training, by reviewing the available and pertinent military and civilian scientific literature.

2 METHODOLOGY

2.1.1 The methodology used was generally based on that outlined by the National Heath and Medical Research Council for the systematic identification and review of the scientific literature (NHMRC, 1999).

2.1.2 The process of gathering previously published research on the capacity of women to improve their physical capacity began with the development of a list of key terms to be used during the interrogation of a range of scientific and defence industry databases.

2.1.3 The key words used were:

- women AND fitness
- women AND resistance
- women AND strength
- women AND ergogenic
- women AND creatine
- women AND caffeine
- women AND performance
- women AND performance improvement
- women AND physical capacity
- women AND training
- women AND injury
- women AND endurance
- women AND power

Each of these key terms was used separately and in combination.

2.1.4 The data bases interrogated were:

- Public STINET
- EBSCOhost
- Springerlink
- Entrez PubMed
- IngentaConnect
- Blackwell Synergy
- Taylor & Francis Group
- Google Scholar

2.1.5 The Public STINET (Scientific & Technical Information Network) was recommended by Dr Joseph Knapik as the most appropriate way of accessing relevant US military research (J. Knapik, personal communication, 17 Jun 2004). The remaining databases are the most relevant and accepted public and subscriber-based tools for investigating this area of research.

2.1.6 The information gathered was generally in the form of peer-reviewed journal articles and unpublished military-specific scientific reports. After evaluating the information presented in these documents, a framework was developed to provide a structure for the literature review. The framework was divided into two major components:

- Training to improve physical performance; and
- Non-training factors that may enhance or impair performance.

Each component contains a range of major subject categories and key topic areas.

2.1.7 Within Component 1, three major subject categories were identified. These were:

- cardiovascular endurance;
- strength, muscular endurance and power; and
- speed and anaerobic capacity.

Where possible, each major subject category was divided into key topic areas of:

- baseline – including a comparison of the physical capacity of untrained young adult males and females;
- non-military training studies of untrained women and elite athletes; and
- military training studies including the capacity of trained women to undertake key military tasks.

2.1.8 Within Component 2, two major subject categories were identified. These were:

- ergogenic aids to performance, including creatine phosphate and caffeine; and
- factors that may impair performance, including menstrual function and injury.

2.1.9 Research involving animals was excluded and unless well justified, research on children and older adults was also excluded. Research on men was generally only included for the purpose of comparison with data collected on women.

2.1.10 The research included in the review was also delimited to findings which related to performance outcomes, and therefore research findings related to biological mechanisms were not included.

2.1.11 The review was limited to English language publications that had been peer reviewed or endorsed by a military agency.

3 TRAINING TO IMPROVE PHYSICAL PERFORMANCE

3.1 Cardiovascular Endurance

3.1.1 Traditionally, cardiovascular endurance activities may be from 5-240 min in duration. Performance in these activities is considered to be governed by a number of key factors (Whipp et al., 1982; Jones et al., 2000). The most commonly reported of these key factors are maximal oxygen uptake ($\dot{V}O_{2max}$), exercise economy and the lactate/ventilatory threshold. The capacity of women to improve these three parameters will be examined in the following sections.

Maximal Oxygen Uptake

3.1.2 Maximal oxygen uptake ($\dot{V}O_{2max}$) is a measure of the amount of energy released and available for use in exercise as a result of aerobic metabolism(Åstrand et al., 1977). In this sense it is often used as a measure of cardiorespiratory fitness and is a major determinant of performance in endurance-oriented activities. It can be measured accurately using a process called indirect calorimetry. This involves measuring the volume and composition of air inspired and expired by an individual during an incremental exercise bout to a maximal level of exertion. It can also be predicted using a number of maximal (e.g. Multistage shuttle run) or submaximal (e.g. Bicycle ergometer tests often undertaken in a gym) endurance-oriented tests.

Baseline Studies

3.1.3 A large number of studies have been published in which the $\dot{V}O_{2max}$ of young adult women has been described. Many of these studies have been examined in the American College of Sports Medicine Position Stand on the Recommended Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness and Flexibility in Healthy Adults (Pollock et al., 1998). In these studies, $\dot{V}O_{2max}$ has been defined either in absolute terms (litres of O_2 consumed per minute: $L{\cdot}min^{-1}$) or in relative terms, generally relative to an individual's body weight (mililitres of oxygen per kilogram of body weight per minute: $mL{\cdot}kg^{-1}{\cdot}min^{-1}$). These authors concluded that the $\dot{V}O_{2max}$ of women is generally less than that of men but these differences are greatly reduced when corrected for fat free mass.

3.1.4 Many of the authors that have described the $\dot{V}O_{2max}$ of men and women have used relatively small samples sizes on which to base their conclusions (Vogel et al., 1986). While acknowledging that $\dot{V}O_{2max}$ may vary from country to country, Vogel et al. (1986) published one of the first large scale studies which described the $\dot{V}O_{2max}$ of men and women. The participants in this study were 1,514 male and 375 female service personnel from the US Army and included individuals ranging in service experience from pre-recruit training to those assigned to infantry combat units overseas. The male and female participants who were assessed prior to their initial recruit training (Males: n=210, Females: n=212) possessed an average (± SD) absolute $\dot{V}O_{2max}$ ($L{\cdot}min^{-1}$) of 3.60 (± 0.50) and 2.18 (± 0.32) and a relative $\dot{V}O_{2max}$ ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$) of 51.1 (± 5.1) and 37.5 (± 3.7), respectively. The mean relative $\dot{V}O_{2max}$ for the female cohort was similar to those reported previously for Canadian female university students (39.1 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$) and Japanese adolescents (39.0 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$) but less than that reported previously for American Physical Education university students (41.8 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$) and Swedish Physical Education university students (47.6 $mL{\cdot}kg^{-1}{\cdot}min^{-1}$) (Vogel et al., 1986). Further analysis of the US Army recruit data (Vogel et al., 1986) revealed that the female to male ratio for relative and absolute $\dot{V}O_{2max}$ was 0.61 and 0.73, respectively.

3.1.5 The data of Vogel et al. (1986) have been supported by those presented by Rayson (2000) who also reported on the $\dot{V}O_{2max}$ of male and female applicants to the British Army. The sample in Rayson's study was even larger than that reported on by Vogel et al. (1986) and included 22,424 males and 3,475 females. However, it should be noted that Vogel and co-workers determined $\dot{V}O_{2max}$ from indirect calorimetry, whereas Rayson (2000) used performance on a multi-stage shuttle run ('beep test') to estimate $\dot{V}O_{2max}$. Nevertheless, given the sample size in Rayson's study, it may be assumed that the group data were relatively accurate. The estimated average (± SD) absolute ($L{\cdot}min^{-1}$) and relative (mL·kg^{-1}·min^{-1}) $\dot{V}O_{2max}$.for the male and female British Army recruits was 3.3 (± 0.6) and 2.2 (± 0.4) L·min^{-1}, and 49.3 (± 5.4) and 36.8 (±5.3) mL·kg^{-1}·min^{-1}, respectively. The ratio of female to male $\dot{V}O_{2max}$ scores in this study was 0.67 and 0.75 for the absolute and relative scores, respectively. These data were very similar to those reported in 1986 for the US Army recruits by Vogel and his colleagues.

3.1.6 The data presented in this section have largely been derived from two major studies conducted in Britain and the US, 6 and 20 y ago respectively. Although these studies were conducted on cohorts of central interest to the ADF (Army recruits) and they showed remarkably similar results, there is a general concern that the $\dot{V}O_{2max}$ of adolescents within the community at large has decreased over recent decades. Therefore, before accepting the data presented by Vogel et al. (1986) and Rayson (2000) as a valid baseline for this section of the review, it is necessary to determine whether there has been an observable decrease in the $\dot{V}O_{2max}$ of children and adolescents in recent years.

3.1.7 Data from two large studies are available from which to explore this issue. Firstly, Tomkinson et al. (2003) reported on the secular trends in the performance of children and adolescents in the years 1980 to 2000 by analysing the performance of 129,882 children and adolescents (up to 19 y) across 11 countries, including 38,380 from Australia but only 456 from the USA and none from Britain. They reported that there was a sample weighted mean decline in performance on a multistage shuttle run (a surrogate for $\dot{V}O_{2max}$) test of 0.4%·y^{-1} and that the decline was similar for boys and girls. The second key study is that published by Sharp et al. (2000) in which they compared the physical fitness of men and women entering the US Army over the period 1978 to 1998. Most importantly, Sharp et al. (2000) reported that the relative $\dot{V}O_{2max}$ of males entering the US Army in 1998 was equivalent to those entering in 1978 (50.6 ± 6.2 mL·kg^{-1}·min^{-1}) whereas the female entrants displayed a 6% greater $\dot{V}O_{2max}$ in 1998 (39.7 mL·kg^{-1}·min^{-1}) compared to 1978. Therefore, the best case conclusion that could be drawn from these two studies is that the $\dot{V}O_{2max}$ of the recruit cohort is somewhat biased and resistant to the change in the general community. Alternatively, one may conclude that on the basis of the data presented by Tomkinson et al. (2003), the $\dot{V}O_{2max}$ scores published by Vogel et al. (1986) and Rayson (2000) may overestimate the $\dot{V}O_{2max}$ of the current recruit cohort by between 2.4 and 8.0% (ie. decline of 0.4%·y^{-1} multiplied by 6 y and 20 y, respectively).

3.1.8 Taking the best case scenario, if one assumes that these data can be reliably related to the Australian population and particularly to Australians who are likely to enlist in the Australian Defence Force, it would follow that the baseline $\dot{V}O_{2max}$ of females in the general young adult population would be approximately 2.2 L·min^{-1} or 37.0 mL·kg^{-1}·min^{-1}. In relative terms, according to the evidence of Vogel et al. (1986) and Rayson (2000), these scores are equal to approximately 60-67% (absolute) or 73-75% (relative) of that of the equivalent male population.

Non-Military Training Studies

3.1.9 The traditional means of improving $\dot{V}O_{2max}$ is to undertake an endurance-oriented training regimen. The American College of Sports Medicine Position Stand on the Recommended Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness, and Flexibility in Healthy Adults (Pollock et al., 1998) indicates that there is no gender difference in percentage improvement in $\dot{V}O_{2max}$ elicited with endurance training. It should be noted, however, that for women where $\dot{V}O_{2max}$ may be limited by both absolute muscle mass as well as by central and peripheral cardiovascular capacity, it is also possible that $\dot{V}O_{2max}$ may be improved by training programs that integrate both resistance and endurance training. This notion will be explored in detail as it has often been suggested that resistance training programs are detrimental, rather than advantageous, to the development of$\dot{V}O_{2max}$ (Paton et al., 2004).

3.1.10 Two approaches may be used to explore the capacity of women in non-military environments to improve their $\dot{V}O_{2max}$. Firstly, one may examine the extent to which $\dot{V}O_{2max}$ is enhanced in previously sedentary women following completion of a standardised training program, generally an endurance training program. Secondly, it is possible to examine the $\dot{V}O_{2max}$ of elite endurance athletes and use these individuals as a benchmark for female $\dot{V}O_{2max}$.

3.1.11 Although the American College of Sports Medicine (Pollock et al., 1998) indicates that there is no discernable effect of gender on the capacity of individuals to improve their $\dot{V}O_{2max}$, detailed exploration of the research cited when making this statement reveals that this conclusion was largely informed by studies conducted upon middle-aged or older adults. Given the younger demographic of Army soldiers, it is necessary to examine the results of studies undertaken on a younger cohort than those quoted by Pollock et al. (1998).

3.1.12 The majority of training studies that have examined the capacity to improve $\dot{V}O_{2max}$ have been conducted on small numbers of individuals (< 20) over a relatively short period of time (< 10 wk) (Jones et al., 2000). In their review of the effect of endurance training on parameters of aerobic fitness, Jones et al. (2000) concluded that although the magnitude of improvement is affected by initial levels, in general these studies have demonstrated that $\dot{V}O_{2max}$ can be improved by 5-10% through training regimes conducted at relatively high intensity (80-100% $\dot{V}O_{2max}$) over 20-30 min per session and 3-5 sessions per week. It should be noted, however, that the ACSM Position Stand (Pollock et al., 1998) advocates a much lower threshold intensity of 40-50% of $\dot{V}O_{2max}$ reserve.

3.1.13 An example of one of these studies was conducted by Eddy et al. (1977). They trained six males and eight females (mean age 20.9 y) described as having an average $\dot{V}O_{2max}$ (females: approximately 38 mL·kg^{-1}·min^{-1}) for seven weeks using either a low intensity continuous protocol (70% $\dot{V}O_{2max}$) or an interval method (repeats at 100% $\dot{V}O_{2max}$) four days per week. They reported an average increase of 5.1 mL·kg^{-1}·min^{-1} or 15% with no difference in the improvement elicited by the men and women. The time course of changes in $\dot{V}O_{2max}$ in response to endurance training was examined by Hickson et al. (1981); they reported that $\dot{V}O_{2max}$ increased by 23% over nine weeks of endurance training, but the majority of the increase (14%) occurred within only three weeks. The magnitude of these responses was in line with those reported by Carter, Rennie, Hamilton et al. (2001) and Carter, Rennie and Tarnopolsky (2001) who noted that women (n=8) who completed a seven week endurance training program (cycling for 60 min·day^{-1} at 60% $\dot{V}O_{2peak}$ over five days per week) increased their absolute and relative $\dot{V}O_{2max}$ by 23.5% (2.29 to 2.83 L·min^{-1}) and 30% (31.9 to 41.5 mL·kg^{-1}·min^{-1}), respectively. The greater percentage relative improvement in $\dot{V}O_{2max}$ in the study by Carter, Rennie, Hamilton et al. (2001) and Carter, Rennie and Tarnopolsky (2001) is due to a decrease in body fat (mean of 0.7 kg) although there was no change in lean body mass.

3.1.14 Notwithstanding the substantial effect of genetics upon performance in endurance sports, a cross-sectional analysis of the $\dot{V}O_{2max}$ of well trained competitive female athletes may also provide some insight as to the capacity of females to improve their $\dot{V}O_{2max}$. A number of studies of well trained and elite athletes were examined for this purpose. Bishop et al. (1998) assessed 24 trained but not elite female cyclists and triathletes (mean age 29.3 y) and reported that they possessed a $\dot{V}O_{2max}$ of 48.1 mL·kg^{-1}·min^{-1} or 2.9 L·min^{-1}. In comparison, Wilber et al. (1997) reported that elite US female off-road and road-cyclists recorded $\dot{V}O_{2max}$ values of 57.9 mL·kg^{-1}·min^{-1} or 3.3 L·min^{-1} and 63.8 mL·kg^{-1}·min^{-1} or 3.9 L·min^{-1}, respectively. These data are very similar to those reported over 40 years ago by Hermansen et al. (1965) who stated that female Norwegian athletes possessed an average $\dot{V}O_{2max}$ of 3.3 L·min^{-1} or 55 mL·kg^{-1}·min^{-1} compared to 2.3 L·min^{-1} or 38 mL·kg^{-1}·min^{-1} for sedentary women. An extensive array of descriptive data were provided by Nevill et al. (2003) who outlined the $\dot{V}O_{2max}$ in 76 elite female British athletes (including world and/or Olympic champions) across seven sports including badminton, heavy and lightweight rowing, middle and long distance running, squash and triathlon. These athletes possessed the following average $\dot{V}O_{2max}$ scores (L·min^{-1} and mL·kg^{-1}·min^{-1}): Badminton: 3.0, 49; Heavyweight Rowing: 4.2, 56; Lightweight Rowing 3.7, 60; Long distance Running: 3.2, 64; Middle Distance Running: 3.6, 63; Squash: 3.7, 54; and Triathlon: 3.8, 58. The relative differences in these scores can be attributed to variations in body size and the varying training and performance demands of the respective sports. However, it can be gleaned from these data that all of these elite athletes recorded $\dot{V}O_{2max}$ scores that were equal to or greater than, 3.0 L·min^{-1} or 49.0 mL·kg^{-1}·min^{-1} and averaged 3.6 L·min^{-1} and 57.7 mL·kg^{-1}·min^{-1}. One should acknowledge, however, that although these scores were likely to have been achieved as a result of intensive and prolonged periods of physical training, they are also likely to have been affected by genetic factors and selection bias.

3.1.15 Therefore, it may be concluded from these non-military longitudinal and cross-sectional studies that women can increase their $\dot{V}O_{2max}$ from a baseline of 2.2 L·min^{-1} or 37.0 mL·kg^{-1}·min^{-1} by approximately 20% to 2.6 L·min^{-1} or 44.4 mL·kg^{-1}·min^{-1} in 7-9 weeks (assuming no proportional change in body composition). A small proportion of these women will be able to achieve $\dot{V}O_{2max}$ scores that are equal to or greater than 3.0 L·min^{-1} or 49 mL·kg^{-1}·min^{-1} depending upon factors such as the type and duration of training, genetics and selection bias.

Military Training Studies

3.1.16 The majority of military training studies that have explored the capacity of women to improve their $\dot{V}O_{2max}$ have been conducted on recruits participating in general military training programs or individuals (often civilian) undertaking specifically designed resistance training studies that may include an endurance training group.

3.1.17 Studies by Daniels et al. (1979), Sharp et al. (2000) and Brock et al. (1997) reported the effect of general recruit training programs upon the $\dot{V}O_{2max}$ of men and women entering the US and British Armies. The recruit training programs generally lasted 6-8 wk and were comprised of a range of marching, circuit training, obstacle course, sporting and running activities. The females studied in Daniels et al. (1979) had relatively high $\dot{V}O_{2max}$ values upon entry to officer training (mean: 46.0 mL·kg^{-1}·min^{-1}) but still improved their mean score by 7.9% over the six weeks and also reduced the difference between the male and female mean scores from 22% to 18%. Similarly, a cohort of 80 females entering basic recruit training for the US Army in 2000 had a $\dot{V}O_{2max}$ of 2.5 L·min^{-1} or 39.7 mL·kg^{-1}·min^{-1} and improved these scores by 7.2% and 6.3%, respectively to 2.7 L·min^{-1} and 42.2 mL·kg^{-1}·min^{-1} (Sharp et al., 2000). In contrast, a study conducted in the British Army by Brock et al. (1997) revealed that a relatively fit group of female recruits with an initial $\dot{V}O_{2max}$ of 45.7 mL·kg^{-1}·min^{-1} or 2.7 L·min^{-1} only increased their $\dot{V}O_{2max}$ by approximately 0.9% (absolute) and 2.1% (relative to body weight) over a six week recruit training period. The limited improvement in $\dot{V}O_{2max}$ reported in this study highlights the issue of diminishing returns when training already relatively well trained individuals. However, it should be noted that this study was conducted in the 1980s (and first reported as a Technical Report in 1988), when the Women's Royal Army Corps (WRAC) still existed and women were trained separately from men during initial training (M. Rayson, personal communication, 27 June 2006). The WRAC was disbanded soon after and thereafter female recruits trained alongside their male counterparts on the Common Military Syllabus (Recruits) (CMS(R)).

3.1.18 An important study was conducted within the British Army by Williams et al. (2002) of recruits undertaking the recently implemented CMS(R) with fully integrated male and female initial training (M. Rayson, personal communication, 27 June 2006). This study was important because it used a training program that was modified from that traditionally administered to recruits, as used in the studies by Daniels et al. (1979), Sharp et al. (2000) and Brock et al. (1997) discussed above, to one that specifically focused upon a careful integration of endurance and resistance training. This study had two key findings. Firstly, the relative $\dot{V}O_{2max}$ of the female participants (n=7) increased from an average of 37.0 to 43.8 mL·kg^{-1}·min^{-1} (18.4% increase); an increase that was in keeping with those previously reported in non-military endurance training studies (Hickson et al., 1981; Carter, Rennie, Hamilton et al., 2001; Carter, Rennie and Tarnopolsky, 2001); but greater than previously reported in general military recruit training studies (Daniels et al., 1979; Brock et al., 1997; Sharp et al., 2000). Secondly, the absolute $\dot{V}O_{2max}$ (ie. L·min^{-1}) increased by 21.2% which was substantially greater than that reported in previous military recruit training studies (0.9 to 7.2%). Specifically, these women increased their absolute $\dot{V}O_{2max}$ from an average of 2.2 to 2.7 L·min^{-1}. The significant increase in absolute $\dot{V}O_{2max}$ can be associated with a marked increase in the participants' lean body mass of 3.8 kg or 8.2% over the training period. This is much larger than that reported previously by Brock et al. (1997) (1.05 kg or 2.4%) as a result of a six week period of general recruit training.

3.1.19 It is important to underline the success of the concurrent strength and endurance training undertaken in the study by Williams et al. (2002), because there is considerable debate as to the impact of concurrent training upon the development of strength and endurance. An extensive review by Leveritt et al. (1999) concluded that concurrent strength and endurance training appears to inhibit strength development when compared to strength training alone. Another review by Paton et al. (2004) concluded that resistance training alone often results in a decrease in maximal oxygen uptake. These conclusions are not supported uniformly, as McCarthy et al. (2002) reported that concurrent performance of strength and endurance training in males does not impair adaptations in strength, muscle hypertrophy and neural adaptation induced by strength training alone. Secondly, Chtara et al. (2005) recently reported that intra-session concurrent training, where the male participants completed strength oriented circuit training immediately after endurance training in the same session, produced superior improvements in aerobic capacity and endurance performance than when the endurance or strength oriented circuit training was completed independently.

3.1.20 It can be concluded from these military training studies that the most effective way to increase both the relative and absolute $\dot{V}O_{2max}$ is to integrate endurance and resistance training in preference to the more general training programs often delivered in military training settings.

Exercise Economy

3.1.21 Exercise economy is expressed as the amount of oxygen used at a given velocity of movement. Studies examining the impact of gender and the capacity of women to improve exercise economy have generally involved running and have fallen into three areas of focus. Firstly, a range of studies have been reported in which the capacity of exercise economy to predict endurance performance was examined. Secondly, studies have explored whether there is a difference between the exercise economy of men and women and thirdly a small number of studies have examined whether exercise economy can be improved through either endurance or resistance training

3.1.22 Jones et al. (2000) identified economy as a key determinant of endurance performance. However, the strength of the relationship between running performance and running economy is dependent upon training status. For example, in highly trained male runners (average 10 km race time: 32.1 min; average $\dot{V}O_{2max}$: 71.7 $mL \cdot kg^{-1} \cdot min^{-1}$), 65.4% of the variation observed in 10 km race time could be explained by variation in running economy (r=-0.81), while the correlation between $\dot{V}O_{2max}$ and distance running time was only r=-0.12 (Conley et al., 1980). Conversely, studies such as that conducted on non-elite women runners by Ramsbottom et al. (1987) reported the correlation between time to complete a 5 km running trial and running economy was r=-0.34 and between running time and $\dot{V}O_{2max}$ was r=-0.80.

3.1.23 Notwithstanding the lesser importance of economy of movement as a predictor of running performance in less well trained women and the fact that women have a lower running and walking economy than men (Helgerud et al., 1990; Daniels et al., 1992; Kang et al., 2002); women do have the capacity to improve their running economy (Johnston et al., 1997; Jones, 1998; Turner et al., 2003).

Baseline Studies

3.1.24 In the case of gender comparison, it has been shown that men used less oxygen ($mL \cdot kg^{-1} \cdot min^{-1}$) at common absolute running velocities, but $\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$) was not different between men and women at equal relative intensities (%$\dot{V}O_{2max}$). Further, when men and women of equal $\dot{V}O_{2max}$ were compared, the men were significantly more economic using any method of comparison (Daniels et al., 1992). While data obtained during running are of interest, it is likely that data obtained during walking are of even greater interest to the ADF. Two such studies have been conducted by Kang et al. (2002) and Pivarnik et al. (1990). Kang et al. (2002) examined the economy of women and men walking at 4.68 $km \cdot hr^{-1}$ over a range of gradients (0%, 5%, 10%, and 15%). They reported that there was no difference in the economy of men and women while walking at 0% and 5% gradients but the women were between 10% and 12.5% less economical ($mL \cdot kg^{-1} \cdot min^{-1}$) than men when walking at the higher gradients. These data contradicted those reported by Pivarnik et al. (1990) who reported no difference between the economy of men or women walking either up hill (5% or 10%) on level ground or down hill (-5% or -10%) at 4.8 km·hr^{-1}. Although the men and women studied by Pivarnik et al. (1990) were not of equal aerobic fitness, they were of similar aerobic fitness ($\dot{V}O_{2max}$: male: 61 mL·kg^{-1}·min^{-1}, female: 53 mL·kg^{-1}·min^{-1}) and were more aerobically fit than those studied by Kang et al. (2002). Given these differences between the participants in the two studies, Kang et al. (2002) hypothesised that less aerobically fit women walk up hill with lower economy than the men, however, when the levels of aerobic fitness are approximately equal, the economy of walking is also similar.

Non-Military Training Studies

3.1.25 The comparison of the data from the studies of Kang et al. (2002) and Pivarnik et al. (1990) implies that women can improve their economy of movement with training. The capacity of individuals and women in particular, to improve their economy of movement has been demonstrated in a number of studies (Johnston et al., 1997; Jones, 1998; Paavolainen et al., 1999; Millet et al., 2002; Turner et al., 2003). These studies have all examined running economy but have used a range of training techniques (strength training and endurance training) that have ranged from short term (six weeks) to long term longitudinal case studies over five years.

3.1.26 The short term studies (typically 6-10 wk in duration) have largely investigated the impact upon running economy of varying forms of strength training undertaken in conjunction with continued endurance training. The strength training has often involved heavy resistance training or plyometric training.[1] For example, studies on low to moderately well endurance trained women have demonstrated improved running economy (approximately four percent) as a result of heavy resistance or plyometric training (Johnston et al., 1997; Turner et al., 2003). Unfortunately, the validity of these findings is reduced by a failure to equate the training volume between the strength/endurance training group and control group (usually endurance training only). However, a well controlled study conducted by Paavolainen et al. (1999) on elite male cross-country runners demonstrated that when total training volume was equated over a nine week training program, five kilometer running performance and running economy were significantly improved in the strength-endurance trained group (3.5% and 8.6%, respectively), whereas no changes were observed in the endurance-only training group.

3.1.27 While short-term strength focused training has been shown to improve running economy, longer-term endurance training has also been shown to improve running economy. One such study was a longitudinal case study conducted by Jones (1998). Jones reported the changes in running performance, $\dot{V}O_{2max}$ and running economy of a world-class female runner over a five year period. In particular, it was noted that 3000 m running performance improved 8% over this period despite $\dot{V}O_{2max}$ falling from 73 to 66 mL·kg^{-1}·min^{-1}. Importantly the improved performance was associated with an increase in running economy of 9.4% at 16 km·hr^{-1}.

Lactate Threshold

3.1.28 Lactate threshold has been reported to be an important factor affecting endurance performance (Jones et al., 2000). For example Bishop et al. (1998) demonstrated that in a group of well trained females, one-hour cycling performance (average power output on a cycle ergometer) was more highly correlated with lactate threshold (r=0.84) than $\dot{V}O_{2peak}$ (r=0.55). These data are supported by those published as early as 1979 by (Fay et al., 1989) when they reported that mean running velocities achieved by moderately to highly trained female runners ($\dot{V}O_{2max}$: 59.7 ± 5.3 mL·kg^{-1}·min^{-1}) over distances between five and 16 km were highly correlated with lactate threshold (r=-0.84 to -0.94).

[1] Plyometric training involves maximal contractions immediately following a rapid stretch of the involved muscles, such as that which occurs when jumping upwards immediately after jumping down from a height.

3.1.29 For the purpose of this review, given that the various lactate threshold related variables (lactate threshold and fixed blood lactate concentrations) respond similarly to exercise training (Weltman et al., 1992) and are highly correlated (Yoshida et al., 1987), the specific definitional basis of the lactate threshold determination will not be discussed or identified, in keeping with the approach taken by Londeree (1997) when discussing the effect of training on lactate threshold.

Baseline Studies

3.1.30 Untrained females ($\dot{V}O_{2max}$: 36-42 mL·kg^{-1}·min^{-1}) have been reported to possess a lactate threshold that is between 38-44% of $\dot{V}O_{2max}$ (Henritze et al., 1985; Yoshida et al., 1987). However, lactate threshold values (mean ± SD) as high as 58.9 ± 3.3% $\dot{V}O_{2max}$ have also been reported for untrained women using similar methodologies to determine the threshold values (Demello et al., 1987). Where data are presented that enable a comparison to be made between the lactate threshold of untrained men and women, it appears that untrained men may have a slightly higher lactate threshold than untrained women (as a percentage of $\dot{V}O_{2max}$). For example, Demello et al. (1987) reported that untrained men and women possessed lactate thresholds of 66.5% and 58.9% of $\dot{V}O_{2max}$, respectively, however the difference was not statistically significant.

Non-Military Training Studies

3.1.31 The effect of training on lactate threshold has been explored in numerous studies; many of which have been examined and incorporated into a meta-analysis by Londeree (1997). Londeree concluded that endurance training at or above lactate threshold clearly improved lactate threshold in sedentary subjects. However, Londeree also concluded that the conditioned subjects displayed smaller, nonsignificant changes in lactate threshold than sedentary subjects, and that if significant changes were to occur, it would require training at a much higher training intensity. Of note was that Londeree did not report that the impact of training upon lactate threshold was affected by gender.

3.1.32 Cross-sectional and longitudinal data can be examined in order to gain an appreciation of the magnitude of change in lactate threshold that can be expected in response to endurance training. Demello et al. (1987) reported cross-sectional data in which they observed that untrained women possessed a lactate threshold equal to 58.9% $\dot{V}O_{2max}$ while trained female distance runners possessed a lactate threshold equal to 73.1% $\dot{V}O_{2max}$. Henritze et al. (1985) conducted a 12 wk longitudinal study in which 33 young (mean age ± SD: 23.0 ± 3.5 y) women with average fitness ($\dot{V}O_{2max}$: 41.1 mL·kg^{-1}·min^{-1}) were trained on a cycle ergometer at an intensity equal to 69 W above their personal anaerobic threshold. They reported that these women increased their lactate threshold from 40% to 57% of $\dot{V}O_{2max}$ as a result of participating in the training program ($\dot{V}O_{2max}$ pre- vs post-training did not change significantly).

3.2 Strength

Baseline Studies

3.2.2 Reviews have been published by Laubach (1976) and Pheasant (1983) which focused upon the relative difference in strength between men and women. Laubach (1976) reviewed nine studies and reported that the upper body strength of women averaged 56%, lower body strength 72% and trunk strength 64% of the values obtained from men. Similarly, Pheasant (1983) reviewed 112 sets of isometric strength data and reported that women averaged 58%, 66% and 62% of the strength scores reported for men for upper body, lower extremity and trunk, respectively.

3.2.3 Some of the most comprehensive data sets outlining both absolute and gender-relative strength scores were reported by Rayson (2000). He reported strength scores for 22,424 male applicants and 3,475 female applicants to the British army. Mean scores were reported for static back strength, static lift and dynamic lift. Mean (± SD) absolute scores for these tests were: Static Back Strength: males 90.7 ±16.5 kg, females 64.7 ± 11.2 kg; Static Lift: males 122.2 ± 26.0 kg, females 82.5 ± 18.1 kg; Dynamic Lift: males 54.9 ±11.2 kg, females 34.7 ± 7.8 kg. The female to male ratio for the tests were: 0.71 (static back strength), 0.68

(static lift) and 0.63 (dynamic lift). Patterson et al. (2004) reported that average female (21-25 y) performance on a vertical jump test (a test of leg strength and power) was 35.6 cm compared to 57.2 cm for males of the same age. These data were collected between two and three decades after those reported by Laubach (1976) and Pheasant (1983). However, they indicated that the ratio of female to male scores continues to be between 0.60 and 0.70. Rayson (2000) stated that the 90th percentile for females on the dynamic lift strength test equates to approximately the 15th percentile for males, or alternatively, that less than one percent of the strongest women can match the strength of the average man. These data give some understanding of the normative spread of data for relatively untrained women versus untrained men.

Strength Training Studies

3.2.4 Although a large number of published studies have described the strength differences between males and females (as evidenced by the numbers of data sets reviewed by Pheasant (1983), comparatively few studies have been reported that have systematically examined the capacity of women to improve their strength. These studies can be allocated to one of three categories. The first category is comprised of those studies that report the impact of a short term (up to 16 wk but generally 8-12 wk) resistance training program upon the strength and power of the female participants. These studies have been conducted by civilian researchers and have explored the impact of a range of resistance training forms such as concentric (muscle shortening) and eccentric (muscle lengthening) movement patterns. The second category is those studies that have been conducted within a military environment and have explored the impact of a standard training program, normally general recruit training, on the overall fitness (including strength and power) of females. These studies have generally been conducted in the 1970s and 1980s by researchers within the US military and in the 1990s by researchers within the British military. The final category of studies is specific resistance training studies conducted within a military environment. These studies have generally been conducted over 12-24 wk and have involved untrained participants.

3.2.5 Before exploring the three categories in detail, it is important to overview major integrative studies that have provided advice on the dose required for strength development. Two key reviews have been published that can inform this matter. The first is the American College of Sports Medicine (ACSM) Position Stand on the Recommended Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness (Pollock et al., 1998). These recommendations have been made for adults in an ‘adult fitness’ setting. In order to improve strength, the ACSM recommends that a minimum of one set of 8-10 exercises involving major muscle groups of 8-12 RM[1] or to near fatigue should be completed; although greater improvements may be achieved with additional sets (up to four) and greater resistances (6-12 RM) using periodisation techniques. A meta-analysis of 140 studies by Rhea et al. (2003) concluded that training with a mean intensity of 60% of 1 RM elicits maximal strength gains in untrained participants, while 80% 1 RM is most effective in those who are trained. Untrained participants gained most from training three days per week, while trained individuals experienced maximal gains when training two days per week. Finally, both untrained and trained individuals experienced maximal strength gains when completing four sets of each exercise.

Non-military Female Strength Training Studies

3.2.6 A large number of peer-reviewed studies were identified in the published literature that focused explicitly upon the determination of the capacity of women to improve strength as a result of participation in a strength training program within a non-military environment. Extensive reviews on selected aspects of strength training for female athletes have been published by Holloway et al. (1990) and by Knapik et al. (1996a) and Knapik et al. (1996b). These publications have typically reported the effect of training programs conducted on young civilian women aged 20-30 y over 6-16 wk (Capen et al., 1961; Mayhew et al., 1974; Wilmore, 1974; Wilmore et al., 1978; Oyster, 1979; O'Shea et al., 1981; Gettman et al., 1982; Hunter, 1985; Cureton et al., 1988; Staron et al., 1991; Butts et al., 1994; Staron et al.,

[1] RM: Repetition Maximum = the greatest weight that can be lifted a defined number of times. For example 10 RM is the greatest weight than can be lifted 10 times.

1994; Stone et al., 1994; Ben-Sira et al., 1995; Higbie et al., 1996; Roth et al., 2000; Massey et al., 2005). As such, these papers report on ‘early phase’ adaptations to strength training (Massey et al., 2005). The papers explored the response of women to strength training and examined the effect of factors such as the type of training (eccentric, concentric, self paced, variable repetitions and variable resistance) upon specific performance tests. In general, these papers reported increases in the strength of the female participants of between 15% and 40% over the duration of the respective studies (2-4% per week).

3.2.7 The question arises as to which forms of training result in the greatest increases in strength. Examples of studies that have been conducted on women and have compared the response to differing forms of strength training in a non-military environment include those conducted by Higbie et al. (1996) (eccentric vs concentric training), Massey et al. (2005) (varied range of motion for bench press), Schroeder et al. (2004) (high intensity: 125% 1 RM vs low intensity: 75% 1 RM concentric), Ben-Sira et al. (1995) (concentric, eccentric, conventional, supramaximal eccentric) and Stone et al. (1994) (high resistance/low repetitions, medium resistance/medium repetitions, low resistance/high repetitions). While each of these studies reported an improvement in strength over time, the only notable differences resulting from the various forms of training were that strength gains tend to be specific to the form of eccentric or concentric training (Higbie et al., 1996) or form of resistance (high, medium or low) (Stone et al., 1994) and that full range of motion bench press is best developed using a training form that empasises a full range of motion (Massey et al., 2005). In general, these studies simply serve to reinforce the notion of training specificity.

3.2.8 An example of the simplest form of these studies is that reported by Ben-Sira et al. (1995). These authors explored the impact of an eight week strength training program undertaken by university physical education students who had not previously been engaged in heavy resistance training. The participants were allocated to one of five groups: eccentric only, concentric only, conventional, supramaximal eccentric or control. They undertook a controlled program of knee extension resistance training over eight weeks using an initial resistance of 65% 1 RM (3 sets, 10 reps). Each group displayed significant improvements in 1 RM knee extension strength of between 14 and 23% or between 1.8 and $2.4\%\cdot wk^{-1}$. Although the greatest improvement was seen in the surpramaximal eccentric training group, no statistically significant difference was reported in the improvement reported between the four training groups. It should be noted that this study, in keeping with many such studies conducted in this area, suffered from an apparent lack of statistical power to detect significant differences between the various training groups due to small sample sizes (8-12 women per group). Nevertheless, Ben-Sira et al. (1995) did demonstrate that novice strength trained women can increase their strength by approximately two percent per week during the early phase of a strength training program.

3.2.9 A better powered study (19 participants per group) that also explored the rate of strength increase by novice strength trained women undertaking different forms of strength training programs (eccentric or concentric) over a 10 wk period was reported by Higbie et al. (1996). These authors noted that strength training (3 sets of 10 reps of quadriceps training conducted three times per week) resulted in a performance enhancement that was somewhat specific to the form of training undertaken; improvements were between 2.3 and $4.5\%\cdot wk^{-1}$ for the concentric and eccentric trained groups, respectively; and that these improvements were the result of both muscle hypertrophy and neural adaptation.

3.2.10 Staron et al. (1994) also completed a training study for a short period of time (eight weeks) where the training was conducted twice per week using either 6-8 RM and 12 RM programs (one each per week) incorporating squat, leg press and leg extension exercises. In general, they reported performance data similar to those reported by Higbie et al. (1996) and Ben-Sira et al. (1995) where both absolute and dynamic strength increased significantly after a short period of time (approximately four weeks). The improvements reported by Staron et al. (1994) were, however, considerably greater than those reported previously. They reported absolute increases in 1 RM (kg) leg press, leg extension and squat of 159.1% ($19.9\%\cdot wk^{-1}$), 185.5% ($23.2\%\cdot wk^{-1}$) and 148.5% ($18.6\%\cdot wk^{-1}$), respectively. The results were comparable for both sexes.

3.2.11 In comparison to these short term studies, over 30 years ago Brown et al. (1974) demonstrated that female athletes respond favourably to prolonged periods (up to six months) of resistance training. However, longer term resistance training programs have been criticised as lacking enough variety to maintain sufficient stimuli to maximize the training effect (Fleck, 1999).

3.2.12 Kraemer and his colleagues conducted one of the few long-term, well controlled strength training studies on women (Kraemer et al., 2003). They explored whether a periodized approach to resistance training could be used to optimise the improvements in strength, power and performance of female athletes by training 30 female US college tennis players three days per week for nine months. Three training groups were formed: periodized (P), non-periodized (NP) and control (C: tennis only). Although the training programs differed over time, the total training volume during each week was similar. Kraemer et al. (2003) noted that, "the major difference between the two programs was that the periodized group rotated loading schemes (4 to 6 RM with longer rest intervals, 8 to 10 RM, and 12 to 15 RM) over successive workouts on Monday, Wednesday, and Friday, respectively; whereas the non-periodized training group utilized a traditional moderate-intensity loading scheme (8-10 RM) where the relative intensity remained constant." They demonstrated that the females who participated in either of the training programs displayed greater increases over the nine month training period than the tennis only control group in 1 RM over a range of strength and power tests/variables including peak power (W) on a 30 s Wingate cycle ergometer test (P: 12.0%, NP: 17.9%); grip strength (P: 7.8%, NP: 10.8%); jump height (P: 50%, NP: 37%); 1RM leg press (P: 19%, NP:17%) bench press (P: 23%, NP:17%), and shoulder press (P: 24%, NP: 23%); as well as tennis specific performance tests for serve, forehand and backhand ball velocities. However, although the participants in the periodized program displayed superior performance over their non-periodized counterparts in a range of tests at the six month time point, after nine months of training all of the tests of strength and power showed a non-significant difference between the groups. Nevertheless, the periodized training group elicited greater improvements than the non-periodized group on the tennis specific tests such as serve velocity at both the six and nine month time points. Fat free mass increased and fat mass decreased as a result of the training programs but there was no significant difference in these measures between the training groups. Further, no improvements were made in sprinting speed and agility, and relative maximal aerobic power decreased over the nine month training period.

3.2.13 In conclusion, the untrained females who participated in these studies demonstrated significant increases in strength over a short period of time (less than eight weeks) of at least 2-4% per week. Longer term training studies resulted in strength improvements of up to 24% and improvements in power of between 12 and 50%. These changes were specific to the type of training undertaken (concentric vs eccentric) and were achieved by training at between 4-12 RM.

General Military Training Studies Including Strength Components

3.2.14 These studies have been conducted by research groups in the US and Britain. Three of the US studies were conducted in the 1980s with two follow-up studies published in 1995 and 2000. One of the three early general military training studies that reported on the effect of basic training upon the strength of female recruits was conducted by Knapik et al. (1980). They reported that seven weeks of training (Basic Initial Entry Training) significantly improved maximal voluntary isometric strength of the upper torso, leg extensors and trunk extensors of the female participants by between 9.3% and 15.9% ($1.3\text{-}2.3\%\cdot wk^{-1}$). Although these isometric tests have little functional relevance, they are a general indicator of strength improvement. These gains were seen to be greater than those achieved by male recruits on comparable tests and this was thought to be due to the lower initial strength level of the females. Further, the males recorded greater absolute strength levels than the females but when these were expressed relative to lean body mass, both sexes were able to exert similar relative amounts of force. This suggested that the difference between the sexes was primarily accounted for by differences in muscle mass.

3.2.15 A follow up study was conducted by the same research group within the US military (Daniels et al., 1982). They tracked the aerobic power and muscle strength of a small group of male (n=11) and female (n=7) officer cadets over their first two years of enlistment. Strength was measured using an isometric test as was the case in the study by Knapik et al. (1980). Daniels et al. (1982) concluded that although both groups increased their strength over this period, even extended military training did not enable females to significantly narrow the difference from male cadets in absolute muscle strength and aerobic power.

3.2.16 A third early study by the same research group (Teves et al., 1985) also explored the impact of a 10-12 wk period of training (US Army Basic Combat Training followed by Advanced Initial Training) on the muscular strength, aerobic fitness and body composition of 970 male and female soldiers. This study reported similar findings to those reported above by Knapik et al. (1980), in that they demonstrated that women were able to increase their isometric strength by between 10% and 19% (1.0-1.9%$\cdot$wk^{-1}) on tests for hand grip strength and isometric upward pull. Dynamic strength on tests such as the incremental dynamic lift to 152 cm and 183 cm increased by 12% and 14%, respectively (1.2-1.5%$\cdot$wk^{-1}).

3.2.17 The two more recent US studies were reported by Westphal et al. (1995) and Sharp et al. (2000). These studies were more focused upon the impact of the recruit training upon the strength of the women than were the earlier studies. Westphal et al. (1995) recruited 158 females who were undertaking Basic Combat Training (BCT) over an eight week period in order to gain a better understanding of the impact of the BCT on the performance and the nutritional status of women. Although not stated explicitly, it is assumed that the training program was similar to that undertaken by the women in the studies by Knapik et al. (1980) and Teves et al. (1985), which largely involved road marching and Army PT. Measures were recorded for dynamic strength, isometric strength, power, anthropometry and load carriage capacity (18.2 kg for 91.4 m) before and after the BCT. Westphal et al. (1995) reported that scores on the performance measures increased over the eight week training period by 4-15% and these were accompanied by an increase in fat free mass of 1.9 kg (4.4%). The improvements in strength reported by Westphal et al. (1995) were somewhat lower than those reported by Knapik et al. (1980). Closer examination reveals that Knapik reported changes in isometric scores whereas the scores reported by Westphal et al. (1995) were for dynamic strength and functional measures such as 1 RM bench press and load carriage. In this sense, the smaller improvements may be considered to have greater functional relevance.

3.2.18 The most recent and in many ways, the most interesting, study conducted by the US Army into the effect of recruit training upon fitness in general, and strength in particular, was conducted in 1998 by Sharp et al. (2000). The interesting aspect of this study was that it not only explored the effect of an eight week recruit training study upon physical fitness of 80 females and 91 males, but it also compared these data with those collected during 1978 to 1983 on similar cohorts of recruit soldiers. The training program undertaken in 1998 was general in nature and included road marching, obstacle courses, confidence courses and 3-5 day.wk^{-1} of general physical training. As a result of the eight week recruit training program, the females displayed improvements in isometric strength (2.7-6.8%), dynamic strength (3.4%), absolute maximal oxygen uptake (7.3%) and fat free mass (3.9%). Further, the improvement in dynamic strength of the women was of a magnitude that was very similar to that reported by Westphal et al. (1995). Although small, these improvements were relatively greater than those observed for the male recruits, but the males continued to display higher strength and absolute $\dot{V}O_{2max}$ scores than the females. For example, the female/male performance ratio increased from 0.576 to 0.596 for upper torso isometric strength, from 0.532 to 0.575 for dynamic lifting strength and from 0.627 to 0.658 for absolute $\dot{V}O_{2max}$ as a result of the eight week general recruit training program.

3.2.19 As noted above, Sharp and her colleagues compared the data collected in 1998 to those collected between 1978 and 1983 in an attempt to shed light on whether the recruit cohort was any more or less ‘fit’ than those entering the US Army approximately two decades previously. The strength of the recruits in 1998 was comparable to, or greater than, those in 1978-1983, however there was an increase in the percentage of body fat (approximately 2-3 percentage points) and the absolute fat free mass (approximately two kilograms) in the more recent cohort. Sharp (2000) concluded that, “while the percent body fat is higher now than it was previously, $\dot{V}O_{2max}$, muscle strength and fat free mass is comparable to or better than trainees 15-20 y ago".

3.2.20 An associated, but non-training based study was conducted by Harper et al. (1997). This study examined the capacity of women who had completed both BCT and advanced individual training as medical specialists to undertake a pack march over 10 km carrying total loads of 18, 27 and 36 kg in the shortest time possible. These women were recruited for this study as their specialty involves carrying a pack loaded with medical equipment. Although the women performed the loaded march at a speed which was up to 21% slower than that of a male cohort, the important finding was that the females were still able to march at a rate that was in excess of that required by the US Army doctrine (4.1 $km.hr^{-1}$ vs 4.0 $km.hr^{-1}$) while marching with loads up to an average of 59% of body weight and using packs that were not designed for use by women.

3.2.21 The first study to specifically examine the effects of basic training on physical fitness and strength of female British Army recruits was reported by Brock et al. (1997). The study was similar to those conducted by the US military in that it examined the effect of a six week basic training program involving 73 female recruits on a range of fitness parameters including isometric and dynamic strength. It is important to note that the recruits were exposed to a training program that was designed to enable them to pass a 2.4 km run in less than 13 min 45 s (29 y and under). Therefore the training program was largely focused upon recruit PT (11.3 hr) and endurance training (8.7 hr) along with other activities such as games, obstacle training, swimming and testing. Despite the training program apparently focusing upon developing endurance capacity, the recruits exhibited significant improvements in isometric strength (grip strength) and dynamic strength (incremental dynamic lift to 152 cm) of 15.9% and 10.1% (2.7 and 1.7%$\cdot wk^{-1}$), respectively. The improvement in strength demonstrated in this study was slightly greater than that reported in the US studies by Teves et al. (1985) Knapik et al. (1980), Westphal et al. (1995) and Sharp et al. (2000) in 7-12 wk of basic training.

3.2.22 Two partner studies were conducted in addition to that undertaken by Brock et al. (1997) on recruits to the British Women's Royal Army Corps. These were conducted by Harwood et al. (1999) on female British Army Officer Cadets and by Williams et al. (1999) on recruits, and explored the impact of initial training on material handling ability as well as physical fitness. As has been noted above (paragraph 3.1.17) , the study of Brock et al. (1997) was conducted when initial training of women was conducted separately from men, whereas that of Williams et al. (2002) was undertaken with recruits undertaking the Common Military Syllabus (Recruits) (CMS(R)) with fully integrated male and female initial training (M. Rayson, personal communication, 27 June 2006).

3.2.23 The study by Harwood et al. (1999) on British Officer Cadets is similar in some respects to those conducted in the US by Daniels et al. (1979) and Daniels et al. (1982), in that the cohort was comprised of officer cadets and that it involved a prolonged training period (44 wk for the British Officer Cadets and two years for the US Officer Cadets). The training program comprised endurance training (mainly marching), battle PT (mainly assault course), basic PT (mainly gym skills) and swimming. It is clear that there was no designated or specifically designed resistance training component, other than body weight resistance exercises, within the 44 wk program. Harwood et al. (1999) commented that when viewing the combined male and female data, the changes in fitness achieved over the 44 wk training program were "modest and equivocal". In general, the changes noted for the females were greater than those observed for the males. Specifically, the females increased their aerobic fitness by 10%, strength by 1.5-17% and muscular endurance by 44-200%[1]. All of these changes were statistically significant. The reductions in body fat and gains in fat free mass for the females were 13.1% and 5.5%, respectively; and both changes were statistically significant.

3.2.24 The Officer Cadets were also required to undertake a large range of military tasks for which there were predetermined pass standards. These tests included a single lift of an ammunition box to either 145 cm or 170 cm; carry two plastic water cans each weighing 20 kg for as long as possible; lift, carry for 10 m and place at a height of 145 cm a weighted

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[1] Note: The 200% increase in performance was for heaves where the women increased from a very low average of 0.7 to 2.0 heaves per person.

box (10, 22 or 44 kg depending upon trade) for 10, 15 or 20 min depending upon trade; complete a loaded march over 12.8 km (carrying a rucksack of 15, 20 or 25 kg, depending upon trade). At the completion of the training program, the female cadets were able to perform the majority of the military tasks to the required standard. Notable exceptions were that the females had high fail rates for the most arduous single lift task of 44 kg to 170 cm (100% fail); the most demanding 2 × 20 kg water can carry standard of 210 m (25% fail); and the most arduous lift, carry and place (145 cm) task (44kg): 50% fail. It is likely that the high failure rates on these tasks reflects both the females' generally lower level of strength and their smaller stature placing them at a mechanical disadvantage when attempting to place loads on high surfaces. A further conclusion that may be drawn from these data is that the female Officer Cadets who completed a strenuous, but general, training program were able to satisfactorily complete all but the most arduous military tasks to the required standard. Interestingly, although it was reported that five percent of available personnel-days were lost as a result of injury, the incidence of injury among male and female Officer Cadets was similar. However, male and female officer cadets were trained in separate platoons (M. Rayson, personal communication, 27 June 2006), and this may have influenced the observed injury rates. The only performance measure shown to be significantly related to injury incidence was the 2.4 km run time, with the men and women who sustained injuries having slower run times than those who did not.

3.2.25 The study by Williams et al. (1999) added to that published by Brock et al. (1997) by exploring the effect of basic recruit training on manual handling ability as well as physical fitness. The training course in this case was conducted over 11 wk as opposed to the six week course reported upon by Brock et al. (1997). Williams and his co-workers (1999) reported on the performance 57 recruits (47 male, 10 female) undertaking the recently implemented CMS(R) with fully integrated male and female recruit training. The training consisted of 71 40-min sessions as opposed to the 51 training sessions undertaken by the recruits in the study by Brock et al. (1997), as the recruit training period had been lengthened during the intervening period. The training involved endurance (running) activities, circuit training (high repetition, low resistance exercises using all major muscle groups), sport, swimming, agility training and manual handling activities (safe technique instruction). The manual handling tasks were similar to those undertaken by the Officer Cadets studied by Harwood et al. (1999). In brief, these tasks included maximal box lifts, repetitive lift and carry tests and loaded march tests. General fitness tests included tests for aerobic fitness (multistage shuttle run test), isometric strength (38 cm upright pull) and dynamic strength (incremental dynamic lift to 145 cm). Kinanthropometric measures were also made to enable percent body fat (bioelectrical impedance) and fat free mass to be estimated. The males and females in the study adapted to the training stimulus in a similar manner. The only difference between the sexes was that the females lost more body fat than the males (-4.1% body mass vs -2.4% body mass). In percentage terms, the improvement exhibited over the 10 wk training program by the 10 women tended to average between 4% and 13% (0.4 to 1.2%$\cdot$wk^{-1}). Although the women responded in a manner similar to that displayed by the males, they uniformly performed to a level that was less than that of their male counterparts. The women were able to perform at a level equal to 44% of the males on the box lift to 145 cm test and between 64 and 81% of the male average score on the remainder of the manual handling tasks and general fitness tests.

3.2.26 In conclusion, it appears that the training regimens undertaken by female recruits in the US and Britain resulted in modest improvements in the fitness of the recruits. This is not surprising given the general nature of the recruit training program. The programs tend to focus upon sport participation (particularly in Britain), marching and general circuit type training. The females involved in these studies demonstrated a capacity to improve their strength by approximately 3-15% and increase their fat free mass by 2-4%. Importantly, where military materials handling tasks were assessed, the recruit females were able to satisfactorily complete all but the most strenuous tasks such as high lifting and carrying and lifting a heavy load.

Military Training Studies with a Specific Focus upon Strength Training

3.2.27 A small but important group of studies has been identified that has reported the effects of strength training programs upon both strength test performance (1 RM) and also upon the capacity to perform various military tasks (Murphy et al., 1978; Knapik et al., 1996b; Knapik et al., 1996a; Harman et al., 1997; Kraemer, 1999; Williams et al., 2002). These studies have been conducted over periods of time spanning 3-26 wk and have involved training in a military environment by both civilian and army trained women.

3.2.28 These studies were focused on determining whether women who undertook specifically designed strength training programs would be able to not only improve their physical capacity, but also improve their capacity to perform a range of key military tasks, such as lifting and loaded marching, that are generally performed by women to a standard that is substantially less than that achieved by their male counterparts.

3.2.29 The most specific studies are those published by the US military reporting research conducted under the auspice of the Defence Women's Health Research Program. The first of these was published in 1996 by Knapik and Gerber and investigated the influence of physical fitness training on the manual-handling capability and road-marching performance of female soldiers. This study built upon an earlier study in which Murphy et al. (1978) reported that women undertaking a three week strength and running training program were able to increase their training load on tasks such as squats and dead lift by 9-40%, and importantly were able to satisfactorily complete a howitzer loading task (lift, carry and load a howitzer shell weighing 44 kg). While the study of Murphy and Nemmers was the first to explore these issues, it was conducted with few experimental controls and limited assessment of the key variables of interest.

3.2.30 The training employed in the studies by Knapik et al. (1996a) and Knapik et al. (1996b) emphasised muscular strength and endurance exercises since this training was considered most likely to improve manual-material handling (MMH) capability. In addition, the program included aerobic training since this form of training was thought to be necessary to improve the range of other tasks that a soldier must perform. The authors trained 21 women drawn from various health specialities (13 completed all phases of the study) for 14 wk. The training comprised of one hour per day, three days per week strength training and two days per week of interval running training. The resistance training program consisted of nine traditional free-weight exercises (power clean, dead-lift, squat, upright row etc). The mass lifted was selected to enable each participant complete 10 repetitions, using 75% of 1 RM as a guide. The participants also performed push-ups (two days per week) and sit-ups (three days per week). The cardiorespiratory endurance training program involved five weeks of running where the distance covered increased from 2.4 km to 4.8 km. In weeks 6-14, the continuous running training program was supplemented by an interval running program (one day per week) that consisted of 4 x 400 m repeats on a 1:1.5 work:rest ratio (decreasing to 1:1 at end of week 14). As a result of completing this training program, the women significantly increased their performance on a variety of strength tasks by between 16 and 19% (1.1 to 1.4%$\cdot$wk^{-1}). Specifically, the women increased the mass they could lift from the floor to knuckle height by 19% (average of 68 to 81 kg) and from floor to chest height by 16% (average of 49 to 57 kg). The women also improved their performance on a strength-endurance task (lifting a 15 kg mass as many times as possible in 10 min) by 17% (average of 167 to 195 times). These improvements in strength and strength-endurance translated into a four percent improvement in the time to complete a five kilometre road march while carrying a 19 kg load (44.7 to 43.1 min, p=0.02). It was also reported that while the participants' body mass did not change as a result of completing the training program, their body fat mass was significantly reduced by nine percent (p=0.036) and fat-free mass significantly increased by six percent. It is important to note that the training program resulted in seven reported injuries, four of which were recurrences of injuries that were present before the study. These injuries resulted in three of the participants being removed from the study (one who incurred a new injury and two who experienced a reccurrence of an existing injury). The authors concluded that, "a short term physical training program, conducted about one hour per day, five days per week can substantially improve female soldiers' MMH capability, result in a small improvement in road-marching ability, and result in favourable changes in body composition (increased fat-free mass and decreased body fat)".

3.2.31 It is important to note that this study employed a general strength training program that was not specific to the MMH tasks. The authors acknowledged that task-specific training programs (largely conducted with male participants) such as those conducted by Asfour et al. (1984), Guo et al (1992) have been shown to result in very substantial and much larger increases in MMH performance than the general program used in the current study (26-99% vs 16-19%). The increased performance in MMH was thought to have resulted from improved manual handling technique, neural adaptation as well as muscle hypertrophy (Knapik et al., 1996b; Knapik et al., 1996a). Nevertheless, Knapik et al. (1996a) and Knapik et al. (1996b) contend that such improvements are specific to individual tasks, and they propose that the general training programs have a positive impact upon a large range of MMH tasks. Knapik and Gerber also compared their data with those of Sharp et al. (2000) who conducted a similar training study with male soldiers. Comparisons between the two studies revealed that while the women possessed an absolute strength level that was 67% of their male counterparts, both studies resulted in similar relative improvements in performance of strength and strength-endurance tasks. However, the absolute increase in male lifting performance was approximately twice that achieved by the females, and therefore the gap in absolute strength became wider.

3.2.32 Knapik et al. (1996a) and Knapik et al. (1996b) also explored the extent to which the strength training program would have impacted upon the capacity of the women to complete military tasks that incorporated a substantial lifting component. They reported that as a result of their increased strength, the women in the study would have been able to successfully complete 98% of tasks that have a lifting to knuckle height component compared to 92% before participating in the study (15 extra tasks). Further, after training the women would have been able to complete 88% of the tasks that involved lifts from floor to chest compared to 79% of the tasks before training (21 extra tasks).

3.2.33 The second in this series of three major studies conducted by the US Army Research Institute of Environmental Medicine under the auspices of the Defence Women's Health Research Program was conducted by Harman et al. (1997). The study examined the effects of a specifically designed physical conditioning program on the load carriage and lifting performance of female soldiers. Whereas the previous study in this series Knapik et al. (1996a) and Knapik et al. (1996b) explored the impact of a general fitness training program lasting 14 wk upon strength and performance of strength oriented military occupational tasks by women, the study by Harman et al. (1997) expanded the training format to include general fitness training, running, backpacking and specialised drills such as interval running, sandbag lifting and carrying and heavy box lifting. In this sense, the training involved both task-specific military training and general training. This study was also expanded in time to include 24 wk of training and the training time was increased from one hour per day in the Knapik et al. (1996a) and Knapik et al. (1996b) study to 1.5 $hr \cdot day^{-1}$.

3.2.34 A sample size of 40 was sought in order to meet the calculated statistical power requirements as well as allowing for program drop out. A total of 46 women were recruited to the study, 32 of whom completed all aspects of the training and assessment program. It is important to note that most of the volunteers (all but one) were civilians working at the base at which the study was located. All volunteers who passed a pre-medical assessment were accepted into the study as there was no pre-established fitness standard or age limit.

3.2.35 The training program involved weight training four days per week, running two days per week, varied drills two days per week and backpacking one day per week. The weight training exercises incorporated the particular body movements used in lifting and load carriage and followed a periodized approach (four week macro-cycles). The program was implemented using a 'multiple mini-circuit' approach that involved high intensity exercises (beginning with 10-12 repetitions per exercise set) completed in sets lasting approximately 30 sec with 90 sec recovery. The running program centred upon a 3.2 km run completed after the weight training program. The backpacking training was conducted at 6.4 $km \cdot hr^{-1}$ over an eight kilometer course (75 min total time). The load carried was chosen by the participants but by the final week of training the loads ranged from 11.4 to 34 kg.

3.2.36 The testing program included a wide range of occupationally related tasks, non-occupational tasks and anthropometric assessments. The occupationally related tasks included tests of maximal occupational lift capacity (floor to 75 cm – table height; floor to 132 cm – truck bed height and 75 cm to 152 cm – work surface to high shelf), tests of repetitive lifting (maximal number of times a 18.2 kg box onto a 132 cm high surface in 10 min), tests of repetitive lift-carry-lift (number of times a 18.2 kg box could be lifted from the ground, carried 7.6 m and lifted onto a 132 cm surface in 10 min), tests of maximal load transport speed (min time to carry a 34 kg back pack over a 3.2 km variable terrain course, min time to cover 3.2 km while pulling a 50 kg trailer). Non-occupational testing included muscular strength/endurance testing (repeated 45.5 kg, 36 cm squats at 37.5 reps·min^{-1} to volitional fatigue), vertical jump test and standing long jump test. Anthropometric variables of interest were measured using dual energy x-ray absorptiometry (DEXA) as well as a range of kinanthropometric measures (widths, circumferences, skinfolds, body weight and height).

3.2.37 Harman et al. (1997) reported that the intense 24 wk training program outlined above resulted in a range of statistically and operationally significant improvements in the physical capability of the participants. In summary, it was reported that the strength of the women (as measured by 1 RM box lift to three different heights) increased by between 30 and 47%. For example, the average box weight able to be lifted to the back of a truck (132 cm) from the ground was 53.6 kg and equated to 81% of the weight lifted by a sample of active duty Army males. Strength/endurance was seen to increase by an average of 32% (106 to 140, 18.2 kg boxes lifted in 10 min) and performance on a more complex strength/endurance task that involved lift, walk and place increased by 17%. Finally, the speed at which the female participants were able to walk over a 3.2 km ‘mixed-terrain’ course while carrying a 34 kg pack increased from 5.4 to 7.0 km·hr^{-1} (22%). Most importantly, Harman et al. (1997) concluded that the percentage of the study participants who qualified to undertake ‘very heavy’ Army jobs increased from 24% to 78% as a result of undertaking the intense, six month training program which incorporated a mixture of task specific and general training. Harman and his co-workers (1997) did, however, comment that there was a substantial level of variability in the rate of improvement displayed by the female participants to the program and that five of the drop-outs were due to acute injuries, the most serious being a tear of the anterior cruciate ligament. It was also of interest to examine the supplementary data that Harman and his colleagues presented on a range of psychological variables. Most striking was that the female participants reported a strong desire to continue to exercise and substantially increased their self confidence as a result of participating in the training program.

3.2.38 The third, and largest set of research projects undertaken by the US military to address the capacity of women to improve their physical performance capacity was a three year investigation undertaken by Kraemer. Three reports were presented on this research program (Kraemer, 1996; Kraemer, 1997; Kraemer, 1999), the first two being progress reports and the final report being an integration of the findings across the entire research program. While the study by Kraemer. is a logical extension of the studies conducted by Knapik et al. (1996a) and Knapik et al. (1996b) who implemented a 14 wk general strength training program coupled with a moderate running program, and the intense 24 wk mixed training program implemented by Harman et al. (1997), it was specifically designed to explore the impact of a weight training program focused upon upper body strength development versus a general weight training program on strength and the capacity to undertake a range of US Army strength-oriented, task-specific assessment tests. One hundred and twenty previously untrained civilian women were recruited into the study. One hundred non-resistance trained men were also recruited to participate in the study as a control group.

3.2.39 The study was justified on the basis that other studies such as those by Cureton et al. (1988) and Jetté et al. (1990) that have attempted to explore and understand the capacity of women to improve their physical performance in general and strength-oriented performance specifically, have utilized unsophisticated strength training programs, and have only been conducted for relatively short periods of time. Kraemer (1999) justified the study’s emphasis upon upper body conditioning by referencing his previous research which examined the effects of upper body strength training in male soldiers on load bearing and performance in the US Army Physical Fitness Test (APFT). This investigation found that aerobic endurance, upper body strength and upper body power are the primary contributors to satisfactory completion of the APFT and load bearing performance. Moreover, Kraemer (1999) noted that the lower absolute magnitude of upper body muscle tissue is considered to be the primary contributor to the reduced capacity of women to perform tasks requiring strength and power. The longer training period used in this series of studies was justified on the basis that previous studies have generally been limited to approximately 8-12 wk and have demonstrated that any strength development was largely due to neural adaptation (Staron et al., 1994). Kraemer hypothesised that the longer training period was necessary to induce the level of muscle hypertrophy desired and thereby optimise both the neural and hypertrophic response to the strength training program.

3.2.40 In order to meet the theoretical and applied aims of the research program, Kraemer (1999), designed a study that incorporated four experimental weight training groups. Two further groups, an endurance training group and a field training group, effectively acted as control groups. The 100 non-resistance trained men also acted as a control group. The training groups were: 1. Upper body strength/power; 2. Upper body hypertrophy/strength endurance; 3. Total body strength/power; 4. Total body hypertrophy/strength endurance; 5. Endurance training control group; and 6. Field training group. The strength/power groups lifted weights equivalent to 8 RM or lower with long rest periods and the hypertrophy/strength endurance group lifted weights 8 RM and higher and used shorter rest periods. All groups also undertook running training on three days per week for 30-45 $min \cdot day^{-1}$. The endurance training control group completed 25-35 min of aerobic exercise followed by very light and controlled slow speed resistance band exercise on three days per week (alternating). The field training group undertook a program that attempted to transfer the strength improvements gained in the weight training program to a less sophisticated, more logistically manageable field environment. Specifically, the field group undertook a calisthenic/ballistic, plyometric training program. All of the training programs were administered in two 12 wk training cycles that included a two week active rest (recreational physical activity only) between the training cycles. Importantly, the subjects did not specifically train for any of the military occupational tests contained within the assessment battery.

3.2.41 The assessment battery was similar to that employed by Harman et al. (1997) and included military-specific tests as well as general strength tests. The military-specific tests included a 1 RM box lift to 1.32 m, a repetitive box lift test (maximum number of 18.2 kg boxes lifted to 1.32 m in 10 min), and a 3.2 km load carriage test (34.1 kg total load). The general strength tests included a 1 RM squat, bench press and high pull, squat jump, bench press throw, and maximum squat repetition test. Also, a number of US Army physical fitness measures such as push-ups, sit-ups and 3.2 km run time were obtained. An assessment of anthropometry and body composition was also made using manual kinanthropometric as well as magnetic resonance imaging techniques.

3.2.42 The four strength training groups displayed a significant level of muscle hypertrophy over the training period and, in general, this did not plateau over time. There was, however, no difference in the level of hypertrophy elicited between the four strength training groups. Overall, the power training groups (upper body and total body) displayed the greatest improvements in general strength performance. These improvements were often not significantly different from those achieved by the other strength training groups but were different from those achieved by the aerobic trained group. For example, the 1 RM squat increased by 12.1 ± 4.9 kg (26% or $1.1\% \cdot wk^{-1}$) in the total body power trained group over the 24 wk training period compared to 10.0 ± 3.9 kg in the upper body power trained group, 8.5 ± 5.7 kg in the total body hypertrophy group, 9.4 ± 6.0 kg in the upper body hypertrophy group, 9.3 ± 2.5 kg in the field trained group and 1.7 ± 3.1 kg in the aerobic trained group. Importantly, these performances resulted in the mean of the best female resistance trained group (total body power trained) of 47.5 ± 8.5 kg being less than that achieved by the average US Army trained male of 81.0 ± 19.7 kg. However, given the variability in the samples, particularly in the male sample, it is appropriate to state that a proportion of the women would have performed better on the 1 RM bench press than the average US Army trained male.

3.2.43 The power-trained groups tended to display the greatest improvements in the US Army fitness tests. Of note was that the average score achieved on these tests in the power-trained groups equaled or was greater than that achieved by the average US Army trained male.

3.2.44 Following the 24 wk training period, the power-trained groups, particularly the total body power-trained group, tended to display the greatest improvements in performance on the military work tasks. In the case of the 1 RM box lift and the repetitive box lift, it was apparent that the average score in the best performing female group was less than that displayed by the average US Army male. However, it was again noted that the variability in the groups was large and therefore it is likely that many of these women would have produced better performances than the 'average' US Army male. The most striking result was that the upper body power, total body power and upper body hypertrophy trained groups all produced a 3.2 km loaded march time that was equal to that of the average US Army male. This result was achieved by a combination of weight training and low intensity aerobic training in the absence of any specific load carriage training. Finally, it was reported that aerobic training alone did not result in improved loaded march performance.

3.2.45 In general, the training program induced a significant training response. The key finding was that the most effective training program was one that emphasised periodized resistance training using 8 RM and under, and performed in an explosive manner. This program was effective in eliciting gains in all fitness variables and also resulted in continued improvements across the life of the six month training period. It was hypothesised that these gains would be further enhanced by the addition of a plyometric training program. This form of training enabled the women to make significant gains towards matching the performance of the average Army trained male. In particular, the women who completed this training program were able to perform the loaded march test at a speed equal to that of the average male.

3.2.46 It is important to compare and contrast the data published from the studies conducted by the US military to those undertaken within the British military. The British studies have generally been conducted by the research group headed by Rayson (Harwood et al., 1999; Williams et al., 1999; Rayson, 2000; Williams et al., 2002) while an additional study was reported by Brock et al. (1997). These studies are of interest, not only because they provide a means of cross-validating the results published by the US military, but also because they focus upon what may be referred to as two forms of training: firstly the training of recruits via the 'normal' somewhat generalist recruit training programs; and secondly, in a manner consistent with the previously reported US military studies, the intense training of untrained females with programs specifically designed to increase strength and power.

3.2.47 The single study conducted within the British Army that explored the impact of a recruit training program modified to include a substantial resistance training component was conducted by Williams et al. (2002). The study was unique in that it compared the effect of an 11 wk recruit training augmented with strength training against the 'normal' recruit training over the same time period. Importantly, the study included a cohort of females (n=9) as well as a cohort of males (n=43). Unfortunately, the number of females within the sample was small and therefore conclusions made from the study regarding the capacity of females to improve in this environment need to be made with caution. Nevertheless, this is the first study to examine the impact of recruit training modified to include strength training upon both the fitness of females and their ability to perform standard military manual handling tasks.

3.2.48 The modified basic recruit physical training program was identical in duration to that normally conducted over the 11 wk period and included 71 40-min training sessions. The modifications included 28 resistance training sessions, substantially decreasing the number of circuit training (18 to 4), sport (19 to 6) and swimming (9 to 4) sessions, and increasing the number of endurance (mainly running) (7 to 15) and manual handling sessions (2 to 6). Agility training essentially remained unchanged (10 to 8 sessions). It can, therefore, be seen that the modified program was more focused upon the specific training objectives of improving strength, endurance, agility and materials handling capacity. The strength training program was designed to include all major muscle groups and was undertaken twice per week with a focus upon power development (6 RM). This was a marked change from the general circuit training program (which had been substantially reduced) that included high repetition, low resistance exercises.

3.2.49 The study produced some fascinating results. Not only did both the male and female participants significantly increase their dynamic strength to a greater extent than those recruits who completed the 'traditional' basic training program, but they also increased their aerobic fitness and manual material handling capacity more than those who undertook the 'traditional' recruit training. Specifically, the females increased their mean absolute maximal oxygen uptake by 21.2% (5.7% in 'traditional' program), increased their mean fat free mass by 8.2% (3.4%), increased their mean box lift to 145 cm by 12.9% (4.5%), decreased their mean loaded march time by 7.3% (1.0%), and increased their mean dynamic lift to 145 cm by 15.5% (6.0%). Importantly, the authors reported that there was no discernable difference in the rate of injury experienced in the two training programs. Although the modified training program produced better performance outcomes for the females, the improvements were generally matched by their male counterparts and therefore, the relative performance of the trained females remained lower than that of the males and ranged from 39 % (box lift to 145 cm) to 76% (15 kg loaded march over 3.2 km) of the male performances.

3.2.50 These military-specific, strength-focused, long-term studies have demonstrated that the most effective form of training was that which incorporated high-resistance, low-repetition strength training and a modest cardiorespiratory endurance training program. This type of training had a far superior impact upon military materials handling capacity than the more traditional general recruit training program or a dedicated endurance training program. Importantly, this form of program resulted in significant improvements in the strength of females but their performance remained inferior to those elicited from a group of male soldiers. Despite this inferior performance on specific strength tasks, the females were able to complete a key military criterion task, the loaded march, at a speed equal to that of the males.

3.2.51 In the case of the 1 RM box lift and the repetitive box lift, it was apparent that the average score in the best performing female group was less than that displayed by the average US Army male. However, it was again noted that the variability in the groups was large and therefore it is likely that many of these women would have produced better performances than the 'average' US Army male.

3.3 Anaerobic Power and Capacity

3.3.1 While anaerobic power and capacity along with sprint performance are affected by strength, a number of studies have been published that have specifically explored the effect of sprint training on sprint performance, and anaerobic power and capacity, of women.

Baseline

3.3.2 Mayhew et al. (1990) published a comprehensive data set from which they explored the gender differences in anaerobic power tests. They examined the gender difference and interrelationships between the following measures of power: vertical jump; stair climb (Margaria-Kalamen test); sprint (36.5 m dash); leg, back, grip and total body (sum of leg, back and grip) strength (measured on isometric dynomometers). Neuromuscular function was also measured using reaction and movement times as well as an agility run. They concluded that untrained men demonstrated superior performance to untrained women on all tests with the exception of reaction time, with the average percentage difference between the sexes being 36.0%. In particular, the average performance of the women on the 36.5 m sprint was 22.2% slower than that of the men and average vertical jump power of the women was 34.8% less that of the men. Anaerobic power and capacity is also often assessed over 30 s using a maximal test on a bicycle ergometer (Wingate test). Untrained women were also observed to perform poorer than the men on this test with the average difference between men and women being 35% for peak power (greatest amount of power in any five second interval) and 40% less for mean power (across the entire 30 s test period) (Murphy et al., 1986).

Non-military Training Studies

3.3.3 A number of cross-sectional and longitudinal studies have been reported that provide information from which one can determine the effect of training on the anaerobic power, anaerobic capacity and sprint performance of women. National-level sprint-trained women have been shown to produce peak power scores on a Wingate test that were 23% higher than that of untrained women and 39% more than endurance trained women (Jacob et al., 2002). Similarly, the average power output of sprint trained women was 16.9% and 24.7% greater than that elicited by untrained and endurance trained women, respectively (Jacob et al., 2002). These results are in accordance with those published in other studies (Crielaard et al., 1986). Untrained women have also been shown to be able to improve their anaerobic capacity in longitudinal studies. Weber et al. (2002) determined the impact of an eight week high intensity cycle ergometer training period (3 × 2 min intervals at 82.5% (week one) - 100% (week eight) of the workload used to elicit 120% $\dot{V}O_{2peak}$, three days per week) on the Maximal Accumulated Oxygen Deficit (MAOD) (a measure of anaerobic capacity). They reported that the untrained women increased their MAOD by 14% in the first four weeks and a further 5% in the second four weeks of the eight week training program. These improvements were no different to those observed in the same study by a group of untrained men. This was the first study to demonstrate these improvements in women but similar improvements have been demonstrated previously in men in response to intense training (Medbø et al., 1990; Harmer et al., 2000).

4 NON-TRAINING FACTORS THAT MAY ENHANCE OR IMPAIR PERFORMANCE

4.1 Ergogenic Aids to Performance

4.1.1 The use of ergogenic aids in a military operational environment has been investigated extensively. It is recognized that the use of ergogenic aids in a sporting context is often surrounded by concerns regarding the ethical use of these substances. Jacobs et al. (2003) concluded, “cheating in sports is not a concern for the population we work with (Canadian military), but we are, of course, concerned with the health risks of performance-enhancing strategies”. Therefore, this section of the review will examine not only the potential performance benefits of ergogenic aids, but also their potential risk to the health of the users.

Caffeine

4.1.2 Caffeine is the most commonly consumed drug in the world (Antonio, 2004), and as early as 1978 Costill and his colleagues reported on its potential ergogenic effect. Research into the ergogenic properties of caffeine has continued since this time, including investigations into its applicability in military operations (Bell et al., 2003).

4.1.3 Given that there is no effect of gender on caffeine pharmacokinetics (Graham, 2001) this review has included studies that have examined the ergogenic effects of caffeine irrespective of participant gender, but has highlighted the involvement of females in relevant studies. The review has explored the effect of dose, nature of activity and participant sensitivity on exercise performance.

4.1.4 The pioneering study by Costill et al. (1978) demonstrated that after ingesting 300 mg of caffeine 60 min prior to exercise, participants were able to ride at 80% $\dot{V}O_{2max}$ for an extra 14.7 min (Mean ± SE: 75.5 ± 5.1 min to 90.2 ± 7.2 min), an increase in mean performance of 19.4%. Although there have been a number of studies published since which have produced contradictory results to those of Costill and his co-workers, on balance the finding of a positive impact of caffeine on endurance performance has been supported by a number of reviews on this topic (Dodd et al., 1993; Graham, 2001). For example, Graham (2001) concluded that caffeine has a powerful ergogenic effect (particularly when taken as pure caffeine rather than as coffee) at levels that are below the acceptable limit of the International Olympic Committee on events lasting from 60 s to 2 hr, although there is little evidence of an effect on strength. Examples of more recent studies to examine the ergogenic effect of caffeine upon endurance performance include those by Graham et al. (1991), Spriet et al. (1992) and Cox et al. (2002), details of which will now be provided.

4.1.5 Graham et al. (1991) examined the effect of caffeine ingestion on well trained competitive runners (n=7). They assessed the time to exhaustion while running at approximately 85% $\dot{V}O_{2max}$ after the runners received either 9 $mg \cdot kg^{-1}$ of caffeine or a placebo, one hour before exercise. Mean (± SE) endurance time increased from 49.2 ± 7.2 min (Control) to 71.0 ± 11.0 min (Caffeine) or by 44.3%. In a follow-up study on recreational cyclists (n=8), Spriet et al. (1992) assessed the time to exhaustion while cycling approximately 80% $\dot{V}O_{2max}$. Again, the participants were administered either caffeine or a placebo (9 $mg \cdot kg^{-1}$) one hour before exercise. Caffeine ingestion produced a positive effect on seven of the eight cyclists, with the one cyclist not producing positive results, complaining of stomach discomfort, secondary to the caffeine ingestion. The mean cycling times for the caffeine and placebo conditions were 96.2 ± 8.8 and 75.8 ± 4.8 min (26.9% increase), respectively. With the removal of the participant forced to stop due to stomach discomfort, the results were 102.6 ± 7.9 and 78.9 ± 4.7 (30.0% increase), respectively.

4.1.6 The studies by Graham et al. (1991) and by Spriet et al. (1992) examined the effect of caffeine on performance during exercise to exhaustion at a fixed relative exercise intensity (80-85% $\dot{V}O_{2max}$). Cox et al. (2002) used a different form of exercise assessment to determine the ergogenic effect of caffeine. They explored the effect of varying forms of caffeine (1: pre-event: 6 $mg \cdot kg^{-1}$, 2: intra-event: 6 × 1 $mg \cdot kg^{-1}$ every 20 min, and 3: 2 × 5 $ml \cdot kg^{-1}$ Coca-Cola between 100-120 min and during a time trial) on time trial performance completed on a cycle ergometer (7 $kJ \cdot kg^{-1}$) after two hours of cycling at 70% $\dot{V}O_{2max}$. They reported that caffeine enhanced performance during the time trial, irrespective of when it was administered. The mean improvement in time-trial performance was 2.2%; much less than observed during the fixed intensity exercise tests. In summary, Bell et al. (2002) reported that the doses of caffeine studied have ranged from 1-15 $mg \cdot kg^{-1}$ body weight, however, doses in the range of 3-6 $mg \cdot kg^{-1}$ body weight have produced ergogenic effects equivalent to those elicited with higher doses (Raguso et al., 1996).

4.1.7 Despite the general consensus that caffeine produces an ergogenic effect upon endurance performance, there is less certainty regarding the dose timing. A recent study by Bell et al. (2002) sought to clarify this issue for both regular caffeine users and non-users of caffeine. They recruited 21 subjects (13 caffeine users, eight non users) who each completed six rides to exhaustion at 80% $\dot{V}O_{2max}$ after ingestion of either a placebo or $mg \cdot kg^{-1}$ body weight of caffeine. This was done at one, three and six hours after ingestion. It was found that non-users gained a greater benefit from caffeine ingestion than caffeine users. Non-users recorded mean (± SD) times of 32.7 ± 8.4 min, 32.1 ± 8.6 min, and 31.7± 12.0 min from their one, three, and six hour trials respectively. All of these trials were significantly longer than those of the placebo control group. Caffeine users recorded mean (± SD) times of 27.4 ± 7.2 min, 28.1 ± 7.8 min, and 24.5 ± 7.6 min, respectively for their trials. For the caffeine user group, only the trials completed one and three hours after ingestion produced significantly greater endurance times than the placebo control group (one hour post: 23.3 ± 6.5 min, three hours post: 23.2 ± 7.1 min and six hours post: 23.5 ± 5,7 min) . The overall magnitude of ergogenic effect from caffeine resulted in a mean increase in exercise time of 28% for non-users and 19% caffeine users.

4.1.8 Given the military focus of this review, it is important to document the impact of caffeine ingestion upon military tasks. Within the military environment, caffeine has largely been ingested as a strategy to assist in ameliorating the debilitating effect of sleep deprivation on cognitive function (McLellan et al., 2004). However, given the ergogenic effect of caffeine on endurance performance, the impact of caffeine ingestion on military endurance-oriented operations has also been investigated. Studies undertaken in relation to this issue have been reported by the Canadian, US and Israeli military, and have explored issues such as the impact of caffeine on prolonged marching performance (Falk et al., 1989), physical performance following 28 hr sleep deprivation (McLellan et al., 2004) and physical performance at altitude (Fulco et al., 1989). A number of studies have also been explored to determine the combined ergogenic effect of caffeine and ephedrine ingestion (Graham et al., 1991; Bell et al., 1999; Jacobs et al., 2003).

4.1.9 Falk et al. (1989) reported that performance on a cycle ergometer test at an intensity of 90% $\dot{V}O_{2max}$ immediately following a 40 km march in which participants were provided with a caffeine drink (initial dose prior to march: 5 $mg \cdot kg^{-1}$, and additional doses of 2.5 $mg \cdot kg^{-1}$ at the third and fifth hr of marching) was not significantly better than that achieved by a group who ingested a placebo drink. McLellan et al. (2004) reported conflicting results to those of Falk et al. (1989) but they conducted their experiment by combining caffeine ingestion with sleep deprivation. Specifically, McLellan et al. (2004) administered caffeine (initial dose at 21:30 of 400 mg followed by 100 mg doses at 03:00 and 05:00 hr on day two) to determine its effect on sleep deprived Canadian soldiers. They reported that the ingestion of caffeine decreased the mean perceived exertion of a two hour forced march initiated at 22:00 hr on day one and significantly reduced the mean time to complete the first set of a post-march sandbagging task. Performance on the second set of the post-march sandbagging task was not significantly affected by the caffeine ingestion. On day two of sleep depletion (07:00 hr), mean time to exhaustion on a treadmill running test (85% of $\dot{V}O_{2max}$) was significantly enhanced (25.9%) as a result of the caffeine ingestion. A final example of a military focused study was conducted by Fulco et al. (1989). Their study required participants to Ingest caffeine (4 $mg \cdot kg^{-1}$) after exposure to 4300 m altitude for one hour. They reported increased exercise time to exhaustion (79-85% of altitude–specific $\dot{V}O_{2max}$) by 54% (22 to 35 min) but caffeine ingestion did not significantly affect performance on the same test at sea-level or after two weeks of altitude acclimatization. Therefore, these studies have demonstrated mixed results, with caffeine being demonstrated to improve exercise performance after acute exposure to altitude and sleep deprivation but not to significantly affect exercise performance following a prolonged 40 km march.

4.1.10 Although ingestion of caffeine has a range of ergogenic benefits on exercise performance, it is important to examine whether there are any negative side-effects associated with its use. Graham (2001) has addressed this issue and he concludes that:

- there is no evidence of a decrease in performance as a result of caffeine ingestion;
- the extent of caffeine induced diuresis is generally limited to that matching the quantity of fluid ingested and that there is no evidence of caffeine induced dehydration; and
- caffeine ingestion may result in dependency, and withdrawal may be associated with headaches, mood shifts, drowsiness and fatigue.

4.1.11 Researchers from the Canadian Defence and Civil Institute of Environmental Medicine have also examined the combined ergogenic effect of caffeine and ephedrine ingestion. Jacobs et al. (2003) reported that this research has been, “based on speculation that caffeine produces a ‘permissive’ action on ephedrine, both lowering the threshold concentration required for physiological effects of a given concentration of ephedrine”.

4.1.12 Bell et al. (1999) reported that ingestion of 375 mg of caffeine and 75 mg of ephedrine slightly but significantly improved performance (mean of 15.4 to 14.7 min) on the Canadian Forces Warrior Test consisting of a 3.2 km run wearing ‘fighting order’ that weighted 11 kg. This research was followed up by another study that explored the effect of caffeine (4 $mg \cdot kg^{-1}$) and ephedrine (0.8 $mg \cdot kg^{-1}$) on muscular endurance (Jacobs et al., 2003). They reported that these ergogenic aids improved performance on a ‘superset’ consisting of leg press (80% 1 RM to exhaustion) immediately followed by bench press (70% 1 RM to exhaustion). Performance on a subsequent ‘superset’ performed two minutes after the first was not enhanced over that achieved in a control condition. Interestingly, Jacobs et al. (2003) attributed the improved muscular endurance primarily to the effect of ephedrine as there was not additive effect of caffeine ingestion. The caffeine/ephedrine (C+E) treatment increased resting systolic blood pressure (C+E: 156 ± 29 mmHg, Control: 137 ± 12 mmHg) and produced an extreme pre-exercise hypertensive response in two normally normotensive participants of 204/90 and 214/112 90 min after ingesting the C+E dose. It is important, therefore, to note the caution expressed by Jacobs et al. (2003) who stated, “we acknowledge that there are serious risks such as demonstrated by the hypertensive response (to the C+E dose) observed in subjects in this study”.

4.1.13 It may be concluded, therefore, that ingestion of caffeine at a dose of approximately 6 $mg \cdot kg^{-1}$ taken up to three hours pre-exercise may augment performance of females during sustained activities by between 20-30%. There are minimal adverse health effects of caffeine ingestion, although withdrawal from caffeine use may induce symptoms such as fatigue and mood shifts. Further, ingestion of caffeine and ephedrine in combination improves muscular endurance, however, it may pose an unacceptable health risk.

Creatine

4.1.14 The nutritional supplement creatine has become a popular ergogenic aid among athletes in recent years. The effect of creatine supplementation on various fitness components has been examined in numerous studies. The results of these individual studies have been incorporated into a number of extensive review articles (Volek et al., 1996; Bird, 2003; Paddon-Jones et al., 2004; Bemben et al., 2005). In general, it has been proposed that creatine supplementation may increase lean body mass, strength, anaerobic capacity and performance in short-term sporting events (Bemben et al., 2005).

4.1.15 It has already been demonstrated in this review that women tend to have a lower capacity to undertake some physically demanding military tasks due to lower strength and power. It is possible that if creatine supplementation is shown to be a safe and effective ergogenic aid, it may assist women to improve their performance in these key military tasks.

4.1.16 Much of the published research on the ergogenic effect of creatine supplementation centres around its effect when combined with resistance training. A meta-analysis by Nissen et al. (2003), found that creatine supplementation enhances the normal development of lean mass or fat free mass and strength resulting from resistance training. Nissen and Sharp analysed 18 studies that met their predetermined set of experimental criteria. These criteria included the requirements that the studies were at least three weeks in duration and involved resistance training two or more times a week. They did not discriminate on the basis of gender or exercise history although training was recorded as a variable. Closer examination of the studies included in the meta-analysis revealed that three of the studies were conducted on women (two involved trained women and one untrained women) and three studies involved both genders (two involved trained subjects and one untrained subjects). The studies involving women (aged 18-22 y) ranged in duration from two to three hours per week and lasted between four and 13 wks. Overall, the creatine supplementation administered in these studies (to males and females) involved a mean initial or 'loading' dose of creatine monohydrate of 19.4 $g \cdot day^{-1}$ for 5.3 days followed by a mean maintenance dose of 6.7$g \cdot day^{-1}$, and the mean duration of the supplementation was 7.5 wk. Nissen and Sharp concluded that creatine supplementation significantly increased net lean mass with gains of 0.36%$\cdot wk^{-1}$ and strength gains of 1.09% wk^{-1}. Nissen and Sharp noted that they were unable to generalise the effects of training status, age and gender as the lack of repetition of each of these variables precluded any definitive conclusions being drawn.

4.1.17 The effect of gender on the impact of creatine supplementation has been explored in a number of studies (Mihic et al., 2000; Parise et al., 2001; Chilibeck et al., 2004). Most of these studies have explored the combined effect of creatine supplementation and resistance exercise upon the development of lean body mass and strength (Parise et al., 2001; Chilibeck et al., 2004) and it should be noted that they each engaged a limited number of subjects and therefore are likely to have limited statistical power.

4.1.18 Mihic et al. (2000) did, however, explore the potential anabolic effect of creatine supplementation in the absence of a concomitant exercise training program in young males and females. They administered 20 $mg \cdot kg^{-1}$ of creatine monohydrate for five days in a double-blinded fashion and reported that both the males and females increased their fat free mass; however there was a tendency for the males to increase more than the females.

4.1.19 The effect of creatine supplementation upon the development of lean tissue and strength of females has been explored in short-term (approximately six weeks) and longer-term (10 wk) training studies. A short-term training study was conducted by Chilibeck et al. (2004). They reported that although the females significantly increased their strength as a result of participation in a six week strength training program, creatine supplementation throughout the training program did not result in the females significantly increasing their lean tissue mass or muscle thickness (measured via ultrasound). Conversely, the males receiving creatine supplementation did demonstrate a significant increase in lean tissue mass over that achieved in the training placebo condition. It should be noted however, that this study only involved five females in each of the training and control groups. Vandenberghe et al. (1997) conducted a longer-term study (10 wk, three hours per week). They recruited 19 healthy but sedentary females, aged 19 to 22 y, who received creatine supplementation combined with resistance training. Using a placebo group as control, Vandenberghe and co-workers administered a high-dose of creatine monohydrate (20 $g \cdot day^{-1}$) for the initial loading period of four days. The loading period resulted in a significant increase in muscle phosphocreatine (PCr) concentrations of six percent. This increase was maintained through out the 10 wk training period (one hour, three times per week, five sets of 12 reps at 70% 1 RM) with a low-dose creatine monohydrate intake of five grams per day. Following the 10 wk training period, it was found that maximal strength of the muscle groups trained, maximal intermittent exercise capacity of the arm flexors and fat free mass were increased 20-25, 10-25 and 60% more in the creatine supplemented group than the control group, respectively. Following the 10 wk training period, 13 subjects volunteered to continue in a detraining period (Creatine group: n=7, Placebo group: n=6). Low-dose creatine (5 $g \cdot day^{-1}$) supplementation was continued for four weeks and the creatine supplementation group maintained their gains in strength and fat free mass during this period. They concluded that long-term supplementation with creatine enhances the progress of muscle strength during resistance training in sedentary females.

4.1.20 A number of more applied studies have been conducted where creatine supplementation has been integrated into pre-season training or a periodised training sport training program. Brenner et al. (2000) used creatine supplementation for five weeks during a preseason conditioning program for 16 women lacrosse players. Pre- and post-testing consisted of body composition, muscle endurance test, 1 RM bench press and leg extension. Post-testing revealed that the creatine supplemented group produced significantly greater improvements in comparison to the placebo group in 1 RM bench press (Creatine: 6.2 ± 2.0, Control: 0.3 ± 0.8 kg) and decreases in percentage body fat (Creatine: -1.2 ± 0.9, Control: 0.3 ± 0.8%). There were no significant differences between the two groups for the remaining measurements, including fat free mass. Two further studies have been published that support the use of creatine in preseason training programs (Kirksey et al., 1999; Lehmkuhl et al., 2003). Both of these studies involved track and field athletes as subjects. Both studies conducted periodized conditioning programs that involved interval sprints and resistance training. Kirksey and colleagues reported significantly greater increases in the scores in a mixed gender group (16 male and 20 female) for the creatine group than the placebo group for countermovement vertical jump height (7.0 vs. 2.3%), countermovement vertical jump power index (6.8 vs. 3.1%), average cycle peak power (12.8 vs. 4.8%), cycle average power (10.8 vs. 3.1%), cycle total work (10.8 vs. 3.5%), cycle initial rate of power production (30.0 vs. 11.2%), and lean body mass (2.6 vs 0.1 kg). In the study by Lehmkuhl et al. (2003) they established an additional treatment group where the participants ingested creatine in combination with glutamine over an eight week training period. Seventeen men and 12 women participated in the study. The addition of glutamine failed to produce results that were significantly different to the creatine supplement only group, but both creatine groups increased their performance at a significantly greater rate compared to the placebo group on measures such as power output and work completed during repeated (5 × 5 s) cycle sprints, vertical jump and fat free mass. Neither of the studies by Kirksey et al. (1999) or Lehmkuhl et al. (2003) analysed their data to determine whether there was a gender effect.

4.1.21 It has been well established that creatine has the potential to enhance strength, power and lean body mass when combined with resistance training, but what is its effect on performance on endurance-oriented activities? Biwer et al. (2003) reported on the effect of creatine supplementation on performance during submaximal treadmill running interspersed with high intensity-intervals, in men and women. Creatine supplementation significantly increased body mass in men, but had a nonsignificant effect on women. Creatine supplementation did not significantly affect time to exhaustion, ratings of perceived exertion or blood lactate concentrations. Based on these findings, it appears that creatine supplementation has little effect in improving performance in submaximal running with interspersed high-intensity intervals.

4.1.22 Given the capacity of creatine supplementation to increase the stores of energy in muscle (Bemben et al., 2005), a large number of laboratory- and field-based studies have examined the effect of a creatine loading regimen upon various forms of sprint performance. The forms of sprint performance have included 20 m running sprints by elite female soccer players (Cox et al., 2002), jumping activities by male and female athletes (Haff et al., 2000), 100 m sprint performance by male track sprinters (Skare et al., 2001), and swim bench performance by male and female sprint swimmers (Dawson et al., 2002). Each of these studies demonstrated a significant improvement in sprint and/or repeated sprint performance following creatine supplementation and it can be concluded that creatine supplementation for between five days and six weeks seems to augment performance in short-term, high-intensity activities such as jumping and sprinting.

4.1.23 Creatine supplementation may be a useful strategy alongside a PT program for increasing the lean tissue mass, strength and power of women. Most literature shows a loading period of around 20 $g \cdot day^{-1}$ for five days increases muscle storage of creatine. A maintenance load of five grams per day after the loading period maintains this excess creatine storage. Although males appear to gain greater benefits from creatine usage, research has nevertheless shown that females increase strength and sprint performance at a greater rate when supplementing a resistance training program with creatine ingestion. These increases may be up to approximately $0.36\% \cdot wk^{-1}$ of lean tissue and strength gains of up to $1.09\% \ wk^{-1}$.

4.1.24 As noted at the start of this section, the aim was to determine both the potential performance enhancement and the safety of the proposed ergogenic aids. Concerns have been raised regarding the potential negative side-effects of ingesting creatine monohydrate upon gastrointestinal function, renal and liver function, muscle cramping and water retention.

Each of these issues has been addressed in the review of creatine supplementation upon exercise performance by Bemben et al. (2005). The following is a summary of their findings:

- Gastrointestinal upset has been reported upon consuming creatine monohydrate however, it is likely that this is due to the drug being insufficiently dissolved or being ingested immediately after exercise. The safety of long term ingestion of creatine monohydrate has yet to be investigated.
- Studies that have investigated the effect of creatine supplementation upon liver and renal function have reported no evidence of a detrimental effect upon performance of these organs. However, it was recommended that care should be taken if an individual has pre-existing compromised renal function.
- Reports of muscle cramping following creatine supplementation appear to be anecdotal and are not supported by well controlled, blinded studies.
- Changes in body mass may be associated with additional retention of water due to the increased osmotic load resulting from the increased concentration of creatine within the cell.

Bemben et al. (2005) concluded that, “there appears to be no consistent finding of any detrimental effects of creatine supplementation in normal, healthy individuals”.

4.2 Factors that may Impair Performance

4.2.1 While there are a number of factors that could be identified which may impair performance, two particular issues have been chosen for inclusion in this review. Firstly, menstrual function has been chosen because of the range of cultural factors surrounding menstruation; and secondly the area of injury has been highlighted because of the need to ensure that any change to the nature and extent of training in which women are involved does not result in greater risk of injury.

Menstrual Function

4.2.2 Research has been conducted into the effect of menstrual function on areas such as strength, endurance, lactate threshold, fuel oxidation and rating of perceived exertion. This review will overview key findings in each of these areas as they relate to menstrual function and physical performance. The majority of the published research in this area compares the physical performance of women during the follicular phase (generally the mid-follicular point: three days prior to ovulation), and the luteal phase (generally the mid-luteal point 10 days post ovulation). Some studies also examined the performance during menses (often days two or three of menstruation).

4.2.3 Researchers have reported that the strength of women is not affected in different phases of the menstrual cycle. For example, Williams et al. (2005) documented that menstrual phase does not have a differential effect on maximum bench press and leg press strength (1 RM, 30% 1 RM, 60% 1 RM) or rating of perceived exertion. These findings are supported by Rock (1997) who involved female military personal in a study to determine the effect of menstrual cycle phases on muscle function. Rock reported that strength and time to exhaustion were not significantly influenced by menstrual cycle phase, and Galliven et al. (1997) noted that performance in either high- or low-intensity exercise undertaken during the follicular phase was not affected by the time of day in which the exercise was performed.

4.2.4 In a similar manner to the results of research examining the impact of menstrual cycle phase on strength, various studies have also reported that menstrual cycle phase does not have a significant effect upon aerobic power or performance in events and activities that have a substantial aerobic component (Hnatiuk, 1996; Beidleman et al., 1999). Beidleman et al. (1999) reported that menstrual cycle phase did not significantly affect aerobic exercise performance during acute altitude exposure. Hnatiuk (1996) stated that 3.2 km run performance of military personnel was not affected by menstrual cycle phase, and Dean et al. (2003) found that menstrual cycle did not affect lactate threshold, although heat loss was inhibited in untrained women compared to trained women during the midluteal phase (Kuwahara et al., 2005). It is also important to note that healthy untrained women who took oral or injectable contraceptives and those in a control group (eumenorrheic) were able to successfully acclimatise to the heat over seven to eight weeks in a similar manner while undertaking a strenuous exercise training program (Armstrong et al., 2005).

4.2.5 Contrasting results have been reported from studies that have examined the effect of menstrual cycle phase on substrate (fuel) oxidation during prolonged exercise. Campbell et al. (2001) demonstrated that substrate metabolism and exercise performance were influenced by menstrual cycle phase in a group of endurance-trained women. They reported that the rate of glucose appearance and disappearance during the second hour of exercise (70% $\dot{V}O_{2max}$) was significantly higher in the follicular phase than the luteal phase and the subjects performed significantly better (13% improvement) in the follicular phase than the luteal phase. The improved performance in the follicular phase was associated with a greater proportional contribution of carbohydrate to the total energy expenditure than in the luteal phase. However, both the follicular and luteal groups responded in a similar positive manner when they ingested a glucose supplement throughout exercise (19% and 26% respectively, $p<0.05$) compared to control groups. In contrast, Bailey et al. (2000) used carbohydrate (CHO) supplementation in subjects of similar aerobic power during exercise of the same relative intensity (70% $\dot{V}O_{2peak}$) until exhaustion and found that the menstrual phase did not effect performance.

4.2.6 In summary, the available research data indicate that menstrual cycle phase has little impact upon exercise performance requiring strength and short-term aerobic activity. Menstrual function also does not seem to affect heat acclimatization but may affect heat loss in untrained women. However, it is possible that the altered hormonal environment may affect substrate metabolism and thereby result in improved endurance performance in females during the follicular phase relative to that achieved in the luteal phase.

Musculo-skeletal Injury

4.2.7 The aim of this review of literature has been to determine whether women exposed to appropriately structured training regimens can increase their performance so as to enable them to undertake a range of strenuous military tasks. However, It is possible that placing women in an intense training environment may expose them to increased risk of injury. The purpose of this section of the review is to examine the potential injury risk of women involved in physical training.

4.2.8 The most informative data on this subject are collected from large-scale studies that have been conducted to determine the incidence of injury, the mechanisms of injury, risk factors for injury and the effect of programs instituted to off-set these factors and control the rate of injury. Preferably these studies are conducted prospectively; however useful information is also available from retrospective studies.

4.2.9 The majority of studies that have addressed this topic have been conducted in a military environment, however a number of studies have been conducted in a civilian setting.

Non-military studies

4.2.10 Many of the studies and literature reviews that have addressed injuries to women during physical activity focused upon injuries to the lower limbs of women involved in sport and physical activity (Neely, 1998; de Loës et al., 2000; Yeung et al., 2001; Thacker et al., 2002; Leeton et al., 2004) and an examination of three epidemiological studies reveals the reason for this focus. Östenberg (2000) conducted a prospective study on female European football (soccer) players and reported that they experienced 14.3 injuries (missing one practice/game or more) per 1000 game hours and 3.7 per 1000 practice hours. These injuries were predominantly to the lower limbs (knee: 26%; foot 12%; ankle 11%, thigh 11%) and the most significant risk factor for injuries in this population was joint laxity (odds ratio (OR): 5.3). Importantly, the rate of injury was no greater than for male football players but knee injuries were more common amongst the women. The susceptibility of the lower limb to injury during physical activity was confirmed in a study on 10,393 basketball participations by McKay et al. (2001). These authors reported that serious injury was most commonly sustained to the ankle, calf/anterior leg and knee; however the severity of injury was not related to gender, standard of competition, age, height, number of games played per week, amount of training undertaken, type of injury, or the mechanism of injury.

4.2.11 A broad-ranging retrospective study of 2002 running injuries referred to a Canadian sports medicine clinic was reported by Taunton et al. (2002). Overall, 54% of those who presented were women. The most common injuries (% male, % female) sustained were patella femoral pain syndrome (38%, 62%), Iliotibial band friction syndrome (38%, 62%), plantar fasciitis, meniscal injuries (54%, 46%), tibial stress syndrome (43%, 57%), patella tendonitis (57%, 43%), achilles tendonitis (58%, 42%), gluteus medius injuries (24%, 76%) and stress fracture-tibia (40%, 60%). Overall, 42% of the injuries were sustained to the knee, 16.9% to the foot/ankle and 12.8% to the lower leg. Multivariate analysis revealed that the strongest predictor of patella femoral pain syndrome for males and females was young age (<34 y) (OR male: 1.901, female 2.159), while for women being below average height (mean < 157 cm) also resulted in an increased risk of patella femoral pain syndrome (OR: 1.616). The proposition that females are at greater risk of knee injuries than males was supported by de Loës (2000) who reported on a seven year study on the risks and costs of 3864 knee injuries in Swiss youth participants in 12 sports. They reported that knee injuries comprised 10% of all injuries in males and 13% of all injuries in females but their proportional contribution to the costs per hour of participation was 27% and 33%, respectively.

4.2.12 Two reviews were identified that specifically examined the risk factors for exercise-related lower-limb injuries (Neely, 1998) and interventions to prevent lower limb soft tissue running injuries (Yeung et al., 2001). Neely (1998) qualified her findings by stating many of the studies conducted in the field lack consistency of definition and methodology, many are retrospective and it is often not possible to identify the baseline population. It was concluded that there was overwhelming evidence that the risk factors for lower limb injury include female gender, age greater than 24 y, a high body mass or high percent body fat (particularly among military populations), low level of physical fitness at the commencement of training and a past history of injury. Yeung et al. (2001) reported that the most effective intervention to prevent lower limb soft tissue injury was to reduce training load but the effectiveness of stretching exercises and insoles to prevent running injuries was unknown. Finally, it was suggested that wearing a knee brace with a patella support ring may be effective in preventing anterior knee pain associated with running. These conclusions are broadly supported by Thacker et al. (2002), who concluded in a review of four reports comparing methods to prevent shin splints, that shock-absorbent insoles, foam heel pads, heel cord stretching and alternative footwear were not effective in preventing shin splints in sports. Further, in contrast to the effectiveness of graduated training loads in reducing lower limb soft tissue injuries reported by Yeung et al. (2001), Thacker et al. (2002) reported that a graduated running program was not effective in preventing shin splints.

Military studies

4.2.13 A number of studies have indicated that women are at greater risk of sports and training injuries than men even when exposure is controlled (Jones et al., 1993). Bell et al. (2000) attempted to explore the factors contributing to the higher incidence of injury reported for females in both the civilian and military literature. They studied 509 men and 352 women during an eight week basic combat training course (BCT) conducted by the US Army. The women increased their fitness substantially during the BCT course. For example, they increased their estimated $\dot{V}O_{2max}$ by 23% (16% increase for men) and improved their push up score by 156% (54% for men). Unfortunately, in achieving these scores, the women experienced about twice as many injuries as the men and their risk of more serious time-loss injuries was 2.5 times that of the men. Bell et al. (2000) reported that gender was not a significant predictor of injury when initial physical fitness, body composition, age and race/ethnicity were controlled; slow run times was the only predictor of injury. However, it should be noted that in practice on a population basis female recruits are unlikely to match males for physical fitness. The authors also concluded that remedial training for less fit soldiers is likely to reduce injuries and decrease the gender differential in risk of injuries. Almeida et al. (1999) also reported on injury rates in the US military, this time in Marine Corp recruits undergoing an 11 wk (men) or 12 wk (women) training program. The gender-based differential in reported injury was similar to that reported for US Army recruits by Bell et al. (2000) (44.0% of females reporting an injury vs 25.6% of males reporting an injury: relative risk (RR) = 1.72, 95% confidence interval (CI) = 1.29-2.30). However, when these rates were corrected to account for unreported injuries, the difference between the sexes was not significant (53.5% women, 45.5% men, RR = 1.18, 95% CI = 0.96-1.44).

4.2.14 Despite the potential confounding influence of under-reporting identified by Almeida et al. (1999) on injury rates expressed by gender, Geary et al. (2002) painted a particularly disturbing picture regarding the effect of injury on female members of the British military. They reported discharge data from 1985 to 2000 filtered by service and diagnostic category. Overall, they reported that females were more likely to be discharged on account of injury than males (RR = 1.65, 95% CI = 1.30-2.10) and in particular, were 3.34 times (RR, 95% CI = 2.75-4.06) more likely to be discharged for musculoskeletal disease than men. They particularly drew attention to the proposed impact of mixed gender training on the injury rates of women. They also supported strategies such as those introduced by Pope (1999) into the Australian Army. Pope reported that over-striding was a risk factor for stress fracture of the pelvis. He was able to decrease the stress fracture rate from 11.2% to 0.6% by reducing exposure of females to ‘drill’. This rate was further reduced by placing women at the front of the platoon during marching, thereby allowing them to set the stride length.

4.2.15 The data presented earlier in this review identified the need for women to undertake demanding physical training regimens in order to be able to increase their performance to a level required to satisfactorily undertake very heavy military tasks. The risk, however, is that such training will result in a substantial increase in the incidence of training-related injury. This issue was addressed in a report published by Reynolds et al. (2001). They conducted a study in which women were exposed to a 24 wk periodised physical training program designed to improve lifting, load carriage and running performance. The women underwent a challenging physical training program of weight training, running, backpacking, lifting and carrying drills and sprint running. The injury rates reported were similar to those reported in a ‘normal’ BCT course of 2.8 lost-time injuries per 1000 hours of training exposure. While the pattern of injuries was similar to that reported earlier with many injuries being sustained to the lower limbs, Reynolds et al. (2001) also reported a substantial number of days lost due to low back strain. Importantly injuries to the knee and low back were responsible for the greatest number of days lost from training.

4.2.16 The previous paragraphs have identified the incidence of training-related injury in females within the US and British military, and some attention was paid to identifying the associated risk factors. However, it is important to focus specifically upon risks of injury. Knapik et al. (2001) reported on risk factors for training-related injuries among men and women in BCT. They confirmed that women sustained over twice the injury rate of men in BCT and that the significant risk factors for time-loss injury in women were fewer push-ups, slower 3.2-km run times, lower $\dot{V}O_{2peak}$, and cigarette smoking. The risks associated with low aerobic fitness identified by Knapik et al. (2001) support the findings reported previously by Jones et al. (1993) and Jones et al. (1999). Knapik et al. (2003) recognized that it was important to introduce countermeasures to address the high rate of injury among women undertaking BCT. In recognition of the elevated injury risk associated with low fitness status, they introduced a Physical Readiness Training (PRT) program as the US Army’s emerging physical fitness training program. The impact of this program was compared to that of the traditional BCT program (control). Knapik et al. (2003) reported that the male and female participants in the PRT program sustained fewer injuries and experienced a higher success rate on the Army Physical Fitness Test than was achieved by the control group (normal BCT).

4.2.17 The evidence from two recent British studies into injury rates among recruits further demonstrates the confounding of gender and fitness effects. On the one hand, (Gemmell, 2002) compared rates of discharges from the British Armed Forces because of overuse injury under two systems of initial training: the former “gender-fair” policy under which women were given separate training with lower entry and exit standards, and the later “gender-free” policy, whereby identical physical fitness tests were used for selection of male and female recruits and the training program made no allowances for gender differences. The cross-gender (F/M) odds ratio for discharges because of overuse injury rose from 4.0 (95% CI 2.8 to 5.7) under the gender-fair system to 7.5 (5.8 to 9.7) under the gender-free system (P=0.001). The author concluded that this study confirms and quantifies the excess risk for women when they undertake the same arduous training as male recruits, and highlights the conflict between health and safety legislation and equal opportunities legislation (Gemmell, 2002). On the other hand, (Blacker et al., 2005) investigated a wide range of potential correlates of rates of medical discharge and remedial instructors referrals in all junior entry and standard entry phase one training in the British Army over a two year period, and found that whilst multivariate prediction models varied considerably across training courses, gender was absent from all models but one, i.e. that gender per se was not a predictor of injury rates when adjustments were made to control for the effects of other factors. The authors concluded that factors other than gender were more important in predicting both rates of medical discharge and remedial instructors referrals (Blacker et al., 2005).

4.2.18 In summary, it is evident that women have been injured at a greater rate than men when undertaking military training. A major cause of the increased rate of injury has been shown to be lower physical fitness rather than gender per se. Programs that have been instituted to more gradually increase the volume of physical training for those who are less fit have successfully reduced injury rate and achieved set physical performance goals. It has also been advocated that mixed-gender physical training is particularly problematic. More aggressive training programs designed to raise the capacity of women to undertake some of the more physically demanding Army tasks have been shown to incur injury rates similar to other female training programs.

5 SUMMARY

5.1 Introduction

5.1.1 Women are deployed within a range of physically and psychologically demanding roles within the Australian Defence Force (ADF). These include combat roles within the Navy and Air Force and combat support roles within Army. In recent times there has been considerable debate within the Army about the capacity of women to undertake even more physically demanding roles, including participation in the combat arms trades.

5.1.2 Given the high physical fitness standard required of personnel employed within the Rifleman and Airfield Defence Guard trades, the question arises as to whether suitably trained women would be capable of meeting the minimal physical requirements of these trades. This question raises a conundrum in the context of the Australian Army; no women have participated in the Initial Employment Training (IET) for these trades, and so there is no empirical evidence of whether or not women can be trained to meet the minimal physical requirements of these trades. An alternative way of providing some evidence to answer the question is to undertake a comprehensive examination of the information available in the military and civilian literature regarding the capacity of women to enhance their physical performance in the key physical capacity areas of cardiovascular endurance, strength, strength/muscular endurance and power.

5.1.3 Therefore the purpose of this review is to provide advice to the ADF on the capacity of women to improve their physical performance capacity through participation in physical training, with reference to the available and pertinent military and civilian scientific literature.

5.1.4 The materials used in the review were gathered from a range of public and military databases. Key databases include PubMed, an extensive scientific and medical database, and the Public STINET (Scientific & Technical Information Network), which contains all of the publicly released research material generated by the US military.

5.1.5 After evaluating the information presented in these documents, a framework was developed to provide a structure for the literature review. The framework has two major components:

- Training to improve physical performance; and
- Non-training factors that may enhance or impair performance.

5.1.6 Each component contains a range of major subject categories and key topic areas. Within Component 1, three major subject categories were identified. These are:

- cardiovascular endurance;
- strength, muscular endurance and power; and
- speed and anaerobic capacity.

5.1.7 Where possible each major subject category was divided into key topic areas of:

- baseline – including a comparison of the physical capacity of untrained young adult males and females;
- non-military training studies of untrained women and elite athletes; and
- military training studies, including the capacity of trained women to undertake key military tasks.

5.1.8 Within Component 2, two major subject categories were identified. These are:

- ergogenic aids to performance; including creatine phosphate and caffeine; and
- factors that may impair performance including menstrual function and injury.

5.2 Cardiovascular Endurance Maximal Oxygen Uptake

5.2.1 Traditionally, cardiovascular endurance activities may be from 5-240 min in duration; performance in these activities is considered to be governed by a number of key factors. The most commonly reported of these key factors are maximal oxygen uptake ($\dot{V}O_{2max}$), exercise economy and the lactate/ventilatory threshold. The capacity of women to improve these parameters was examined in sequence.

5.2.2 If one assumes that data accessed from other Western nations can be reliably related to the Australian population and particularly Australians who are likely to enlist in the Australian Defence Force, it is apparent that the baseline maximal oxygen uptake ($\dot{V}O_{2max}$) of females in the general young adult population is approximately 2.2 $L \cdot min^{-1}$ or 37.0 $mL \cdot kg^{-1} \cdot min^{-1}$. In a relative sense, these scores are equal to approximately 60-67% (absolute) or 73-75% (relative) of the equivalent male population.

5.2.3 The results from a number of non-military longitudinal and cross-sectional studies indicate that women can increase their $\dot{V}O_{2max}$ from a baseline of 2.2 $L \cdot min^{-1}$ or 37.0 $mL \cdot kg^{-1} \cdot min^{-1}$ by approximately 20% to 2.6 $L \cdot min^{-1}$ or 44.4 $mL \cdot kg^{-1} \cdot min^{-1}$ in seven to nine weeks (assuming no proportional change in body composition). A small proportion of these women will be able to achieve $\dot{V}O_{2max}$ scores that are equal to or greater than 3.0 $L \cdot min^{-1}$ or 49 $mL \cdot kg^{-1} \cdot min^{-1}$ depending upon factors such as the type and duration of training, genetics and selection bias.

5.2.4 A range of military training studies report that the most effective way to increase both the relative and absolute $\dot{V}O_{2max}$ is to integrate endurance and resistance training in preference to the more general training programs often delivered in military training settings.

5.2.5 From an infantry and ADG perspective, given that women often have a lower $\dot{V}O_{2max}$ and that the velocity of movement is the same as for men (as in marching or sustained patrolling), it is likely that low aerobically fit women will be less efficient than their male counterparts but aerobically fitter women may be able to undertake tasks such as prolonged marching and sustained patrolling with an economy of movement that is similar to that of males.

Exercise Economy

5.2.6 Short term strength focused training over 6-10 wk has been shown to improve running economy by between 3.5 and 8.6%. Longer term endurance training has also been shown to improve running economy. Over a five year period a world-class female runner improved her 3000 m running performance by eight percent despite $\dot{V}O_{2max}$ falling from 73 to 66 $mL \cdot kg^{-1} \cdot min^{-1}$. Importantly the improved performance was associated with an increase in running economy at 16 $km \cdot hr^{-1}$ of 9.4%.

Lactate Threshold

5.2.7 Lactate threshold is the workload at which the blood lactate concentration begins to increase from a baseline value. It is considered to represent the maximal exercise intensity one is able to sustain for a prolonged period of time. Cross-sectional and longitudinal data can be examined in order to gain an appreciation of the magnitude of change that can be expected in lactate threshold in response to endurance training. Cross-sectional data have been reported which indicate that untrained women possessed a lactate threshold equal to 59% $\dot{V}O_{2max}$ while trained female distance runners possessed a lactate threshold equal to 73% $\dot{V}O_{2max}$. Longitudinal data indicate that young women with average fitness can increase their lactate threshold from 40% to 57% of $\dot{V}O_{2max}$ as a result of participating in a 12 wk training program ($\dot{V}O_{2max}$ pre- vs post-training did not change significantly).

5.2.8 The ratio of female to male strength scores continues to be between 0.60 and 0.70. It has been stated that the 90th percentile for females on the dynamic lift strength test equates to approximately the 15th percentile for males or alternatively, less than one percent of the strongest women can match the strength of the average man.

5.2.9 The American College of Sports Medicine (ACSM) has provided recommendations on the quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness. These recommendations have been made for adults in an 'adult fitness' setting. In order to improve strength, the ACSM recommends that a minimum of one set of 8-10 exercises involving major muscle groups of 8-12 RM[1] or to near fatigue should be completed; although greater improvements may be achieved with additional sets (up to four) and greater resistances (6-12 RM) using periodisation techniques. Further, it was concluded from data collected in a meta-analysis of 140 studies that training with a mean intensity of 60% of 1 RM elicits maximal strength gains in untrained participants, while 80% 1 RM is most effective in those who are trained. Untrained participants gained most from training three days per week, while trained individuals experienced maximal gains when training two days per week. Finally, both untrained and trained individuals experienced maximal strength gains when completing four sets of each exercise.

5.3 Strength

5.3.1 Untrained females who participated in a number of non-military based studies demonstrated significant increases in strength over a short period of time (less than eight weeks) of at least 2-4% per week. Longer term training studies resulted in strength improvements of up to 24% and improvements in power of between 12 and 50%. These changes were specific to the type of training undertaken (concentric vs eccentric) and were achieved by training at between 4-12 RM.

5.3.2 The general training regimen undertaken by female recruits in the US and Britain results in modest improvements in the fitness of the recruits. The programs tend to focus upon sport participation (particularly in Britain), marching and general circuit type training. The females involved in these studies demonstrated a capacity to improve their strength by approximately 3-15% and increase their fat free mass by 2-4%. Importantly, where military materials handling tasks were assessed, the recruit females were able to satisfactorily complete all but the most strenuous tasks such as high lifting and carrying and lifting a heavy load. The injury rate was also similar for the male and female recruits.

5.3.3 Military-specific, strength-focused, long-term studies of females have demonstrated that the most effective form of training was that which incorporated high resistance, low repetition strength training and a modest cardiorespiratory endurance training program. This type of training had a far superior impact upon military materials handling capacity than the more traditional general recruit training program or a dedicated endurance training program. Importantly, this form of program resulted in significant improvements in the strength of females but their performance on specific strength tasks remained inferior to those elicited from a group of male soldiers. Despite this inferior performance on specific strength tasks, the females were able to complete a key military criterion task, the loaded march, at a speed equal to that of the males.

5.4 Anaerobic Power and Capacity

5.4.1 While anaerobic power and capacity along with sprint performance are affected by strength, a number of studies have been published that have specifically explored the effect of sprint training on sprint performance, and anaerobic power and capacity of women.

5.4.2 Untrained men demonstrate superior performance than untrained women on a range of sprint and tests of anaerobic capacity. In particular, the average performance of the women on a 36.5 m sprint was 22% slower than that of the men and average vertical jump power of the women was 35% less that of the men. Anaerobic power and capacity is also often assessed over 30 s using a maximal test on a bicycle ergometer (Wingate test). Untrained women perform poorer than the men on this test with the average difference between men and women being 35% for peak power (greatest amount of power in any five second interval) and 40% less for mean power (across the entire 30 s test period).

[1] RM: Repetition Maximum = the greatest weight that can be lifted a defined number of times. For example 10 RM is the greatest weight than can be lifted 10 times.

5.4.3 A number of cross-sectional and longitudinal studies have been reported that provide information from which one can determine the effect of training on the anaerobic power, anaerobic capacity and sprint performance of women. For example, national level sprint trained women have been shown to produce peak power scores on a Wingate test that were 23% higher than that of untrained women and 39% more than endurance trained women. Similarly, the average power output of sprint trained women was 17% and 25% greater than that elicited by untrained and endurance trained women, respectively. Untrained women have also been shown to be able to improve their anaerobic capacity in longitudinal studies. Untrained women increased their anaerobic capacity by 14% in the first four weeks and a further five percent in the second four weeks of an eight week training program. These improvements were no different to those observed in the same study by a group of untrained men.

5.5 Non-Training Factors that may Enhance or Impair Performance

Ergogenic Aids to Performance

5.5.1 The use of ergogenic aids in a military operational environment has been investigated extensively. It is recognized that the use of ergogenic aids in a sporting context is often surrounded by concerns regarding the ethical use of these substances. However a representative of the Canadian military concluded, “cheating in sports is not a concern for the population we work with (Canadian military), but we are, of course, concerned with the health risks of performance-enhancing strategies”. Therefore, the review examined not only the potential performance benefits of ergogenic aids, but also their potential risk to the health of the users. The two ergogenic aids examined were caffeine and creatine.

5.5.2 Ingestion of caffeine at a dose of approximately 6 $mg \cdot kg^{-1}$ taken up to three hours pre-exercise may augment performance by females during sustained activities by between 20-30%. There are minimal adverse health effects of caffeine ingestion although withdrawal from caffeine use may induce symptoms such as fatigue and mood shifts. Further, ingestion of a caffeine and ephedrine dose improves muscular endurance, however the ingestion of a dose of caffeine and ephedrine may pose an unacceptable health risk.

5.5.3 The use of creatine supplementation may be a useful strategy alongside a PT program to increasing the lean tissue mass, strength and power of women. Most literature shows a loading period of around 20 $g \cdot day^{-1}$ for five days increases muscle storage of creatine. A maintenance load of 5 $g \cdot day^{-1}$ after the loading period maintains this excess creatine storage. Although males appear to gain greater benefits from creatine usage, research has still shown that females increase strength and sprint performance at a greater rate when supplementing a resistance training program with creatine ingestion. These increases may be up to approximately $0.36\% \cdot wk^{-1}$ of lean tissue and strength gains of up to 1.09% wk^{-1}. There appears to be no consistent finding of any detrimental effects of creatine supplementation in normal, healthy individuals”.

Factors that may Impair Performance

5.5.4 While there are a number of factors that could be identified which may impair performance, two particular issues have been chosen for inclusion in this review. Firstly, menstrual function has been chosen because of the range of cultural factors surrounding menstruation; and secondly the area of injury has been highlighted because of the need to ensure that any change to the nature and extent of training in which women are involved does not result in greater risk of injury to the women involved.

5.5.5 Menstrual cycle phase has little impact upon exercise performance requiring strength and short-term aerobic activity. Menstrual function also does not seem to affect heat acclimatization but may affect heat loss in untrained women. However, it is possible that the altered hormonal environment may affect substrate metabolism and thereby result in improved endurance performance in females during the follicular phase relative to that achieved in the luteal phase.

5.5.6 Women are injured at a greater rate than men when undertaking military training. A major cause of the increased rate of injury has been shown to be lower physical fitness rather than gender per se. Programs designed to increase the volume of physical training more gradually for those who are less fit, have successfully reduced injury rates and achieved set physical performance goals. It has also been advocated that mixed-gender physical training is particularly problematic. More aggressive training programs designed to raise the capacity of women to undertake some of the more physically demanding Army tasks have been shown to incur injury rates similar to other female training programs.

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