University of Alberta

Effects of Police Protective Ensemble on Walking Economy and VO_{2peak} In Female Police Officers

by

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Dedication

This is dedicated to my husband, Samuel,

and

our wonderful children

Samuel Benjamin and Rori Mackenzie.

Without their teamwork and sacrifice, this would not have been completed.

Thank you.

Abstract

To determine the effects of police protective equipment on walking economy and VO_{2peak}, 30 female officers performed two randomized treadmill trials in police protective ensemble (PPE) and physical training ensemble (PTE). The weight of the PPE was (8.5 kg ± 0.6). Exercise consisted of four submaximal (SUB) stages and a progressive phase to measure VO_{2peak}. SUB power output (PO) was higher (13%) in PPE. Absolute VO_2 was higher (18-20%) during SUB exercise in PPE. Officers perceived SUB exercise to be more difficult with PPE. Peak PO and VO_2 were not different, however subjects exercised longer and ran faster in PTE. While ventilation at VO_{2peak} was unchanged, breathing frequency was higher and tidal volume was lower in PPE ($p<0.05$). These results show that PPE increases submaximal energy expenditure and decreases maximal exercise performance, and its effects on breathing patterns during maximal exercise are consistent with restriction of the chest wall caused by the protective vest.

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Chapter One

Introduction

Background to the Problem:

There has been much controversy in North American police departments about the best method for conducting occupational physical testing. It is widely accepted that police work demands that officers maintain a superior level of fitness in order to perform required tasks. The failure to perform these tasks in a safe, reliable, and efficient manner can result in loss of property, injury to civilians or police officers, or loss of life. While the importance of police physical readiness has been well documented and accepted (Collingwood et al, 1995), there is unfortunately, a paucity of research on minimum levels of fitness required to perform the job or how fitness should be evaluated. Answering these questions was beyond the scope of this study. This study attempted to determine whether police protective ensemble (PPE) had any significant impact on the physiological variables associated with walking economy and maximal oxygen consumption (VO_{2max}). There has been no published research to date that has investigated this matter. Physical fitness testing is normally done while participants are dressed in shorts, T-shirt, and running shoes, which will be referred to as physical training ensemble or PTE. On the other hand, police officers on duty normally wear an ensemble that includes uniform clothing and a set of personal equipment required for safe and effective job performance. The uniform consists of T-shirt, short-sleeved shirt, trousers, and steel-toed safety boots (ankle high). The equipment includes a protective vest, and a leather belt that holds the officer's baton, sidearm, radio, extra ammunition, handcuffs, pepper spray, taser, and flashlight. For the purposes of this research, the duty ensemble will be referred to as police protective ensemble or PPE. The weight of the PPE as used by the Edmonton City Police ranges from approximately 7 to 12 kilograms which is consistent with other agencies in Canada.

Statement of the Problem:

Occupational testing is typically done while wearing PTE, while work is performed wearing PPE. I was interested in the extent to which police equipment affects energy expenditure and maximal aerobic work capacity. The subjects in this study were female police volunteers. Female police officers are largely underrepresented in most studies on police fitness, so reporting data on this group will be a valuable asset to the literature. In addition, it was suspected that body size would impact the effects of PPE. And if so, the effects should be most pronounced in smaller female officers.

Purpose:

The purpose of the study was to determine if there were any significant differences in the physiological variables associated with walking economy and VO_{2peak} when comparing exercise in PPE and PTE in female police volunteers. Some key variables evaluated were: walking economy (as seen by $VO_{2submax}$), VO_{2peak}, heart rate, ventilation, and power output. Changes in economy and VO_{2max} were assessed with reference to body size and composition to determine if there were any significant correlations.

Hypotheses:

1. Walking economy and VO_{2max} would be decreased in the PPE condition as compared to PTE.

2. The effect of PPE on physiological variables would be increased with decreased physical size and/or fitness.

Delimitations:

1. In this study, the only variable being manipulated was the testing condition, which was either:

   a. Physical Training Ensemble (PTE): t-shirt, shorts, and running shoes

   b. Police Protective Ensemble (PPE): duty belt, Danner® boots, Kevlar® vest, uniform

2. The study investigated physiological responses to graded exercise in 30 apparently healthy female subjects from the Edmonton Police Service. Each subject underwent three treadmill VO_{2max} tests, one practice test in either PTE or PPE, and one in each of the two testing conditions. The protocol for each treadmill test remained the same.

3. Each subject underwent a Dual Energy X-ray Absorptiometry (DEXA) to determine body composition. Of particular interest were the relative and absolute amounts of fat and fat free soft tissue.

4. It was important that only police officers were included in the sample rather than civilians in police gear. It has been stated in the literature that skill can have an affect on economy, in this circumstance, walking economy (Cavanagh and Kram, 1985). To eliminate that confounding variable, it was important that all subjects were completely familiar with exercising in PPE. As well, police equipment is specially fitted for each individual, so each subject used her own gear. For the above reasons, only police officers were recruited to participate.

Limitations:

Due to the population from which the subject sample was drawn, there were several limitations to this study.

1. The test results may have been limited by the continually changing schedules of police officers on shift work. This caused fluctuations in sleeping and nutritional patterns and could have affected the results.
2. The test results may have been limited by the fitness levels and ages of subjects. It was possible that only the more habitually physically active officers volunteered to take part, and thus created a more homogenous sample than actually existed. A similar trend may also have occurred with age. Older officers may have been less willing to volunteer than younger officers. Also, older officers, like the general population, tend to have more risk factors than younger officers, which could have excluded them from volunteering or participating.
3. The test results may have been limited by the motivation of the subjects to provide a maximal effort.

4. The Kevlar® vests could not be standardized, so there were approximately four various models used. The year of employment of each subject determined which type of vest was issued. If I attempted to standardize the vest, it would have caused the sample group to be very homogenous.

5. Conclusions about the effects of PPE were limited because this study investigated only the cumulative effect of all the equipment. Thus, conclusions could not be made about the impact of the individual pieces of PPE.

Chapter Two

Review of the Literature

Upon reviewing the police related literature, it is evident that, while there is an abundance of anecdotal articles published, there is a distinct lack of research in this area. This may be because much of the research appears to be conducted as in-house studies in which the findings are not published but remain as in-service or government documents. The research that is available generally falls into the following categories: task analysis; police officer characteristics analysis; and, program evaluation. Only the relevant research will be presented.

Legal Issues

The Meiorin case in 1999 has brought the issue of Bona Fide Occupational Requirements (BFOR) to the forefront in physically demanding occupations across Canada. This lawsuit was filed against the government of B.C. for unlawful dismissal of a female forest firefighter for failing an aerobic fitness test, the Cooper's 1.5-mile run, as a condition of employment. The Supreme Court of Canada found in favor of Meiorin. They ruled that the fitness standard set at the 80th percentile for males was discriminatory against women and that the government failed to prove that passing the test was necessary in order to do the job (British Columbia, 1999).

Either the Canadian Human Rights Act or the corresponding provincial human rights statute binds all Canadian police departments. In Alberta, it is the Alberta Human Rights Citizenship and Multiculturalism Act. Whichever jurisdiction a department falls under, the specifications of any of the Human Rights acts in Canada require the "[protection of] individuals from discriminatory practices unless BFOR are established for employment" (Anderson and Plecas, 1999). Discriminatory practices may be evident in situations of adverse impact. However, if an employer can demonstrate that the standard set is a BFOR, then the standard can be maintained (Collingwood, 1995). It is the employer's responsibility, however, to search for other methods of testing that are just as valid but demonstrate less adverse impact. If another method can be found that has less adverse impact, then this method must be used (Maher, 1984; Evans, 1980). BFOR are necessary to protect employees, to ensure that those hired can meet the demands of the job, and to protect the workforce by hiring individuals whose optimum health would reduce the incidence of job-related injuries (Deakin et al, 2000). For a BFOR to be declared, an employer must determine the important aspects of the job, the abilities necessary to perform the job in a safe, reliable, and efficient manner and the employer must determine a method of assessing whether an individual has the abilities identified as being necessary (Deakin et al, 2000).

There are two aspects of proving that a test is legally valid. The first is to prove that the skill or ability being tested is job related. To prove job-relatedness, it must be shown that the skill or ability is fundamental for job performance; this includes testing attributes that are underlying or predictive of these necessary skills or abilities (Collingwood et al, 1995). Examples of underlying dimensions are aerobic capacity, anaerobic capacity, and upper body strength. There are three ways to demonstrate job-relatedness: content validity; construct validity and rational validity (Collingwood, 1995; Deakin et al, 2000; Shepard, 1990). Content validity includes task simulation tests that are comprised of tasks that are representative of essential job functions or duties. These tests generally have high face validity because they appear to be similar to the tasks that one would perform on the job. Construct validity involves identifying underlying variables that are indicative of success in the job tasks deemed to be necessary (Gledhill et al, 2001; Collingwood, 1995). Physical fitness tests rely on construct validation because they measure physiological variables such as aerobic capacity, flexibility, and upper body strength, which are believed to be related to the successful completion of essential job tasks. Finally, rational validity occurs when agencies depend on and adopt the validations made by other departments, assuming that there are a common set of critical tasks among police agencies. This saves police services the expense of conducting their own assessments of police duties and critical tasks (Collingwood et al, 1995).

The second aspect of proving legal validation is proving that the standards or tests are nondiscriminatory with respect to age, gender, or race (Collingwood et al, 1995). However, the purpose of a test is to discriminate on the basis of suitability: between a suitable applicant and an unsuitable one (Collingwood, 1993). As stated above, a standard can be maintained, even if it is discriminatory against age, gender, or race, if it can be proven that it is a BFOR.

Liability

Not only do employers have to be aware of liability arising from inappropriate testing methods, they must also be cognizant of vicarious liability. Vicarious liability refers to a government or police service being responsible for the health of its officers, and their ability to perform their duties (Madison, 1984). According to the Canada Labor Code, Part 2, employers must ensure that their employees are provided a safe environment in which to work and that they are reasonably protected while they are on duty. Failure to provide these things can result in an organization being penalized monetarily, as well as the senior management being charged under the criminal code (Gledhill and Bonneau, 2000). One example of vicarious liability involves the District of Columbia, USA (1989) where a male suspect was shot by a police officer. The court ruled that the male was shot because the officer was incapable of subduing him during an arrest attempt. It was revealed that the police department had not provided any fitness training for the officer in over four years. The suspect was awarded $425,000. Other forms of vicarious liability can involve the following:

a) Negligent retention: hiring an individual that is unfit for the duties required of him/her.

b) Negligent assignment: assigning an officer to a duty that he/she is unfit to accomplish or perform.

c) Failure to supervise: neglecting to enforce mandatory physical requirements of incumbent members.

d) Failure to direct: failing to provide employees with the information or procedures necessary for them to maintain their fitness.

e) Negligent entrustment: entrusting a weapon or a vehicle to an officer that is unfit to handle such tools (Carter, 1982; Gledhill and Bonneau, 2000).

It is obvious that a department's responsibility in regards to employees' physical capabilities does not end when basic training is complete. Failure to monitor the physical fitness of their employees on an ongoing basis opens departments up to significant civil liability.

In addition, without some type of ongoing physical testing and standard maintenance, it is difficult to defend a BFOR. If members currently performing the job are unable to meet the minimum standard, then that standard is questionable as being necessary for the "safe, efficient and reliable performance of the job" (Gledhill et al, 2001). A question that must also be asked is what level of job performance is considered satisfactory? In 1976, the International Association for Chiefs of Police recommended fitness programs for all police officers. In 1987, the Commission on Accreditation for Law Enforcement Agencies required all agencies seeking accreditation must have valid physical fitness requirements for selection and have ongoing valid incumbent agility and fitness requirements. Surprisingly, as of 1995, only 25-33% of law enforcement agencies in the USA have some type of fitness program with only 10-30% being mandatory (Collingwood et al, 1995). In Canada, these values are lower (personal communication with Wiles, D., 2001). In September 2000, a national forum was conducted in Toronto to initiate the groundwork for establishing physical ability tests (PAT)/fitness as a BFOR for police work (Gledhill and, Bonneau, 2000). However, it is unclear whether this has influenced Canadian police departments to implement annual physical evaluations for incumbent members.

Physical Demands Of Law Enforcement

There have been a number of task analyses conducted in Canada into the nature of police work. The task analyses primarily focus on the dynamic, sporadic physical demands as opposed to the daily demands. The activities identified are generally the same across studies (Farenholtz and Rhodes, 1986; Gledhill, 1995; Anderson and Plecas, 1999) and are summarized into 11 categories: walking/standing, running, climbing stairs, jumping, vaulting, crawling, lifting, carrying, pulling/dragging, pushing, and balancing.

In an unpublished task analysis, the Royal Canadian Mounted Police (RCMP) (1996) attempted to elucidate the differences in job functions of female and male RCMP members. They utilized the Surrey RCMP detachment where 35 members, seven of whom were female, were involved. The study included a self-reporting format that continued over 114 shifts. No information was given as to the instructions that members received. The results showed some differences in the activities of the female members as compared to the compiled data of male and female RCMP. For example, some of the distances run by the females were shorter but some of the weights carried and pulled were larger. However, because the male data were not reported separately, gender comparisons are impossible. Also, the sample size of seven females was very small. Further research is needed in this area.

While some task analyses suggests that police work is very physically demanding, a study by Stamford et al. (1978) suggests that police work in not demanding enough to require the maintenance of high fitness levels. They studied 61 recruits: seven females and 54 males, before police training, after training, and one year after training. They found that during training, fitness levels increased while percent body fat decreased. However, after one year on patrol with no supplemental fitness training, body fat was significantly higher and fitness scores returned to pre-training levels or lower. Therefore, while the task analyses show that police work can be very physically demanding, these activities are sporadic and are not sufficient to maintain fitness.

VO_{2max} of Police Officers

Much of the literature relating to police officers has focused on the physical characteristics of officers, including the measurement of VO_{2max}. Franke and Anderson (1994) studied 450 male and 20 female officers in an attempt to determine the difference between habitual exercisers and non-exercisers with regards to cardiovascular disease. They did not separate the data of males and females in their results, which are displayed in Table 1.

Table 1

Mean VO_{2max} for police officers as reported by Franke and Anderson (1994)

Age Categories (years)	**Exercisers VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)**	**Non-Exercisers VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)**
Under 31	55	49
31 – 36	52.5	49
37 – 42	48	43
43 – 48	47.5	42.5
Over 48	46	39

All tests were conducted on a treadmill using either the Bruce protocol or the modified Bruce protocol. The tests were stopped either when the subject reached volitional exhaustion, or when the researchers identified signs warranting termination. The termination criteria were not specified.

Stamford et al. (1978) conducted a descriptive study of the "cardio-respiratory and body compositional fitness variables" of 136 male officers of the Louisville Police Department. VO_{2max} was determined using a discontinuous protocol on a Monark bicycle ergometer. The researchers' criteria of VO_{2max} were an "adequate plateau in oxygen uptake between progressive loads" or an RER ≥ 1. The results are shown in Table 2.

Table 2

Mean (± SD) VO_{2max} for police officers as reported by Stamford et. al. (1978).

Number of Subjects	Average Age (years)	Average VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)
33	25.30 ± 3.82	36.73 ± 5.13
22	34.86 ± 3.28	31.30 ± 4.81
16	43.06 ± 2.91	30.19 ± 6.04
4	53.00 ± 2.16	27.54 ± 5.61

It was concluded that police officers demonstrated an average level of fitness as compared to normative data and that the trend of officers' VO_{2max} decreasing with age was similar to the trend appearing in the general public. Stamford et al. (1978) also concluded that police work was not physically strenuous enough to necessitate higher than average physical fitness.

Wiles (1986) reported the results of a longitudinal study of changes in fitness components over a three-year period involving male members of the Edmonton Police Service. Six fitness components were studied, one of which was aerobic power. VO_{2max} was estimated using a modified Astrand protocol on a cycle ergometer. This was a predictive test based on Fox's equation (1973). The results are summarized in Table 3.

Table 3

Predicted VO_{2max} for male police officers as reported by Wiles (1986)

Age (years) / n	**Predicted Aerobic Power ($ml \cdot kg^{-1} \cdot min^{-1}$)**	
	1982	**1984**
20-24 / n = 80	44.2 ± 4.4	44.0 ± 4.4
25-29 / n = 180	41.7 ± 4.7	42.4 ± 4.9
30-34 / n = 127	39.2 ± 5.3	40.1 ± 5.1
35-39 / n = 116	37.6 ± 5.2	37.8 ± 4.9
40-44 / n = 40	37.6 ± 5.0	37.7 ± 4.9

Wiles concluded that an annual fitness evaluation for police officers was effective in decreasing the trend of declining fitness levels over time.

Metivier et al. (1982) attempted to develop a screening test for police officers for the Ottawa Police Force (OPF). OPF management was required to select the best officers in their department in regards to physical fitness, psychological soundness, and efficiency. The definitions of, and criteria for, each of these terms were not clarified. There were a total of 71 male subjects selected with an average age of 24.9 years and an age range of 18-37 years. Expired gases were collected and analyzed during the final 90 s of each stage of a Bruce treadmill protocol. The results were reported as percentiles so that the standards for the Ottawa Police Department could be established. The results are presented in Table 4.

Table 4

Mean VO_{2max} for police officers as reported by Metivier et al (1982).

Percentile	**VO_{2max} (ml·kg^{-1}·min^{-1})**
95	53.8
50	40.0
5	28.9

The standard for applicants of the OPF was set at the 60th percentile based on this data from OPF's specifically selected male members.

Spitler et al. (1987) examined the physiological characteristics of three female and nine male police officers of the Greensboro Police Department. VO_{2max} was determined using a graded Bruce treadmill test with a termination criteria of volitional fatigue. The results for VO_{2max} were 42.1 ± 8.9 ml·kg^{-1}·min^{-1} for the males and 41.5 ± 8.7 ml·kg^{-1}·min^{-1} for the females. Researchers concluded that, despite their assumption that police officers are bigger and stronger than the average person, the officers they studied were in fact average with respect to aerobic fitness.

Wilmore and Davis (1979) tested 140 males from the California Highway Patrol in a study to validate a physical ability field test. They tested the 70 highest and the 70 lowest ranked officers according to a supervisory ranking system. This ranking system was based on 16 critical job tasks of which only three were physical. The subjects underwent a battery of laboratory tests, including a VO_{2max} treadmill test where either the grade or speed was increased every minute to “symptom-limited volitional fatigue.” The results for VO_{2max} were 39.9 $ml \cdot kg^{-1} \cdot min^{-1}$ and 3.29 $L \cdot min^{-1}$. It is assumed that these results are averages although that was not clearly stated in the paper. The researchers did not find any statistically significant difference between the two groups of officers (highest and lowest ranking) and their performance on laboratory fitness tests. Therefore, they concluded that laboratory tests of fitness were not good screening tools for police officers. In the second part of their study, the researchers recruited 217 males and 13 females to complete two Physical Abilities Tests (PAT). Again, the PATs revealed no significant difference between the low and high-ranking officers. The PATs were developed to simulate the California Highway Patrol working environment. The height of the barriers coincided with the heights of fences along highways and cement barriers between opposing directions of traffic. It does not appear that any task analysis was conducted as a foundation for either PAT. Neither PAT was clearly described in the article. The female data were not reported because the authors decided that the female sample size was too small to draw any conclusions.

Klinzing (1980) studied the physical fitness levels of 15 of the 17 male members of the Cleveland State University Police Department. The average age of the officers was 29.3 ± 5.0 years. One component of the fitness battery was a VO_{2max} treadmill test utilizing a continuous walking protocol with a constant speed of 87.16 $m \cdot min^{-1}$ (3.25 mph) and a 2.5% increase in grade every two minutes. The criteria for VO_{2max} was RER > 1 or O_2 uptake not increasing by more than 50 ml per minute. The results were reported as sigma scale scores and are summarized in Table 5.

Table 5

VO_{2max} for police officers as reported by Klinzing (1980).

Sigma Scale Scores	**VO_{2max} (ml·kg^{-1}·min^{-1})**
99	56.7
50	38.0
1	19.3

The researchers concluded that, compared to the student population these officers were hired to protect, they scored average to below average in the fitness components that were tested. Klinzing did not elaborate on the study conducted on the male students and did not state how large the student sample was.

Pollock et al. (1978) tested 213 male police officers from three law enforcement organizations: Dallas, Richardson, and the Texas Department of Public Safety. All officers were between 21 and 52 years of age. The study was conducted to analyze the fitness levels and risk of coronary heart disease among Dallas and surrounding area police officers. One portion of the study included a VO_{2max} treadmill test utilizing the Bruce protocol. Test termination criteria were not reported. Results were presented as percentile rankings, with the 99th, 50th, and 1st percentiles being reported respectively as: 50.0, 40.7, and 30.8 ml·kg^{-1}·min^{-1} for the officers aged 21-35 years. The officers aged 36-52 years had the following results: 44.0, 32.9, and 27.0 ml·kg^{-1}·min^{-1} for the 99th, 50th, and 1st percentiles respectively. The researchers concluded that the younger group of police officers was comparatively similar to a sedentary population of the same age, while the older group of officers was below average when compared to an age equivalent sedentary population.

Rhodes and Farenholtz (1992) studied 73 male and 25 female police officers from an unspecified police department. The purpose of this study was to determine if there were any correlations between laboratory tests of fitness and the Police Officer's Physical Abilities Test (POPAT), which was developed by Rhodes and Farenholtz in 1985. One laboratory test included in the study was a VO_{2max} treadmill test in which the protocol was an increase of 13.4 $m \cdot min^{-1}$ (0.5 mph) beginning at 134.1 $m \cdot min^{-1}$ (5 mph) until volitional fatigue. The researchers reported the following results: the average VO_{2max} for the male subjects was 3.8 ± 0.5 $L \cdot min^{-1}$ or 44.1 ± 6.79 $ml \cdot kg^{-1} \cdot min^{-1}$, and for the female subjects, 2.5 ± 0.4 $L \cdot min^{-1}$ or 39.0 ± 6.8 $ml \cdot kg^{-1} \cdot min^{-1}$. The researchers concluded that the subjects involved in their study were overweight and unfit.

Physical Abilities Tests (PAT)

Physical ability tests for police are obstacle courses that attempt to closely simulate the conditions and tasks that officers are expected to perform in the course of their duties (Osborn, 1976). There are currently three PATs used in Canada: the Police Officer's Physical Abilities Test (POPAT) in British Columbia, the Physical Ability Readiness Evaluation (PARE) used by the RCMP, and the Physical Readiness Evaluation For Police (PREP) in Ontario (Ontario Government, unpublished). All these courses are designed to duplicate the scenario in which an officer must: a) get to the problem b) physically solve the problem and c) remove the problem (Trottier, Brown, 1994; Bonneau, Brown, 1995).

The POPAT evolved from police task analysis and research conducted on male inmates incarcerated in federal penitentiaries (Farenholz and Rhodes, 1986). The weights used in the push/pull machine were based on the average pushing and pulling abilities of inmates. Inmate data was also used to standardize the POPAT. Not including the object carry, the cut off time was set at 4 min 15 sec, which represents the average inmate time to completion. The distances and activities were based on the original task analysis that Farenholz and Rhodes (1986) conducted with officers over a four-week period. However, there are discrepancies between the data obtained in the task analysis and the inmate study and the values used in the POPAT. For example, the average distance run in the task analysis was 494 m, yet the POPAT is only 400 m long. As well, the pulling and pushing abilities of adult male inmates were tested at 51.4 kg (113.4 lbs) and 53.5 kg (117.9 lbs), respectively, but Farenholz and Rhodes used 36.3 kg (80 kg) in the POPAT (Farenholz and Rhodes, 1986). The reasons for these discrepancies were not explained.

The PARE is a revised version of the POPAT and was adopted by the RCMP in 1991 to screen applicants (RCMP, 1996). In an unpublished government document (RCMP, 1998), the RCMP explained their rationale for modifying the POPAT. They felt that certain aspects of the test were low in face validity and contributed to significant adverse impact, namely the ten consecutive vaults and the time to completion. No data were given to support the validity of these conclusions and the decision to change the test.

A key research study is a Master's thesis by Stanish (1994) from Dalhousie University. The purpose of the study was to compare the PARE against various field tests of fitness in order to identify which field tests would best predict PARE performance. The field tests were: body mass index (BMI), 1-RM leg press, 1-RM bench press, 31.8 kg bench press in 30 sec, 2.4 km walk-run, 40 m sprint, Barrow zig zag run for agility, broad jump, pushups, vertical jump, and sit ups. The subjects included 27 female and 21 male university students and RCMP applicants aged 19-31 years. The researchers did not specify how many of each comprised the sample. The researchers used Pearson product-moment correlation to determine that PARE time was significantly and positively correlated to agility, 40 m sprint, and 2.41 km run, with correlations ranging from 0.73 to 0.66. PARE time was also significantly and negatively correlated to 31.8 kg bench press, broad jump, 1 RM bench press, and pushups, with correlations ranging between –0.71 and –0.61. They concluded that “88% of the variability... [was] accounted for by aerobic capacity, upper body strength and agility” (Stanish, 1994).

In an unpublished paper by Gaul and Wenger (1992), no significant correlation was found between PARE performance and the results of the Canadian Standardized Test of Fitness. As a result, their recommendation was that the PARE not be used to assess fitness. In addition, they were researching the completion times of the PARE using Newfoundland and Saskatchewan RCMP members. Testing occurred four times over a two-year period. Some problems with the subject samples were identified. First, only three to thirteen percent were female RCMP members. In addition, due to members being transferred, injured, or unavailable, only 209 males and 15 females were able to complete all four tests. The data presented was a combination of data from those who completed all four tests and those who completed only one to three of the tests. The results from each test period were compiled from all members tested during that time. The researchers did not exclude the results of members who entered the study late or dropped out early. Thus, the samples reported were neither stable nor consistent. The researchers did find significant gender differences in PARE performance. Of the male subjects, 71% passed the PARE the first time by running it in less than four minutes. On the fourth and last attempt, 78% of the males passed. Only 25% of the female subjects were able to pass on the first attempt and 48% were able to pass on the fourth attempt. An interesting finding of this study was that a small body mass, as seen in many females, prohibited individuals from completing the push/pull portion of the PARE. Researchers explained that this was due to a lack of friction between the floor and the subjects' feet because the individuals did not weigh enough. However, all women were able to carry the 100-pound weight. The researchers felt that this indicated that the women had good upper body strength, but simply lacked the body mass to successfully complete the PARE.

The PREP was developed as a result of a task analysis conducted by Gledhill (1995). The study appeared to be more of a validation study than a task analysis. The officers involved were required to fill out a survey regarding pre-selected activities where they were asked to rank these activities according to frequency and importance. It appears there was no room for documenting those activities that members performed, but which researchers did not include in the survey.

It has been determined that for obstacle course tests, a marked learning effect occurs (Jette et al, 1990). For most subjects tested, the third trial usually results in the best time.

One aspect of physical testing for police officers or applicants that is absent from the literature is some type of validation study. A validation study could help determine whether any of the physical tests currently used in Canada accurately screen for individuals physically capable of performing police duties. Neither the PARE nor the POPAT seem to have undergone this type of scrutiny. The only document to address the issue is Gledhill and Bonneau, (2000) where it is stated that, "Some incumbent police officers feel that the BFOR standards are too low and the standard of new recruit is dropping. The RCMP is getting pressure from some incumbents because some fellow workers can't do all aspects of their job properly." Validation studies are needed in future research.

Walking Economy

Economy has been defined as 'the steady state aerobic demand' (Martin and Morgan, 1992) of submaximal running or walking (Cavanagh and Kram, 1985). Efficiency and economy are often used interchangeably in the literature (Daniels, 1985). There are many factors that affect economy. These include gender, age, speed, stride length, and stride frequency.

Daniels and Daniels (1992) studied elite male and female runners and found that men typically have a 14% higher vVO_{2max} than women. They defined vVO_{2max} as the velocity at which VO_{2max} was reached. At set velocities, the males in their study had significantly lower running economies than the women. In addition, when males and females were matched for VO_{2max}, the males still demonstrated lower running economies. Likewise, when males and females were matched for economy, the males' values for both VO_{2max} and vVO_{2max} were 14% higher. Daniels and Daniels found that vVO_{2max} was a better predictor of running success than either economy or VO_{2max}, regardless of gender. It is unclear if this is a gender issue or a size issue, as Cavanagh and William (1982) found that those with longer anthropometric measurements, such as leg length, foot length, and pelvic width had better economy. Only males were studied so it is unclear whether the same relationship would be seen in women. Other studies have indicated no difference in economy between the genders (Bunc and Heller, 1989; Davies and Thompson, 1979).

Advancing age and decreased flexibility tend to decrease economy (Martin, Morgan, 1992; Daniels, 1985). These two factors are thought to impact each other as it is believed that with advancing age, flexibility decreases. Flexibility influences an individual's gait and thus alters economy.

Speed also impacts economy. There is a U-shaped speed-economy curve for walking which shows an ideal walking speed that would be most economical. Martin and Morgan (1992) reported this speed to be 1.3 m/sec. However, Unnithan and Eston (1990) tested adults and children and found that the most economical speed was generally a self-paced, freely chosen one unique to each subject. It was also reported that the oxygen costs per stride was similar between the two groups at the various speeds. The children obviously took more strides per minute than did the adults at various speeds, which resulted in higher VO_2 values.

Stride Length and Stride Frequency

There are two parameters discussed in the literature that have a significant impact in this study: speed of walking/running and load carriage. The literature deals with how these two factors influence gait patterns, predominantly stride length and stride frequency. Included in some of the research are the differences that speed and load carriage bring about in the magnitude of change in stride length and frequency between men and women.

Both stride length and frequency are thought to be key elements in running economy. Cavanagh and William (1986) found that individuals generally choose a stride length that closely coincides with their most economical stride length. This is called self-optimization. It was found that graphing ΔVO_2 against stride length resulted in a U-shaped curve. The more stride length deviated in either direction from the most economical value, the more VO_2 increased. Sekiya et al. (1997) supported this concept in their research. Twenty-two students, ten males and twelve females, were tested at five speeds; one preferred, two faster, and two slower than preferred. It was concluded that variability in stride length was the least when speed, stride length, and stride frequency were at the preferred values as chosen by the subjects. According to their results, variability in stride length was the least at a rate of 0.006 m/step/min when using the ratio of stride length/stride frequency.

A finding that has implications for my study is that both stride length and stride frequency increase with increasing speed in both males and females (Sekiya et al., 1997; Unnithan and Eston, 1990; Zarrugh, et al., 1974; Charteris, 1998). Zarrugh et al., (1974) was able to show a gender difference in these factors. It was demonstrated that stride length and the ratio of stride length/stride frequency were significantly smaller in females than in males. The difference was attributed to the generally shorter limb length in females. Charteris (1998) found that swing time, absolute contact time, and double support time decreased with increasing speed. The most economical way to increase speed is by increasing stride length rather than stride frequency (Unnithan and Eston, 1990).

Load carriage also affects gait patterns, in particular stride length and frequency. Pierrynowski et al. (1981) studied the effects of load carriage on gait patterns in male subjects. Loads carried around the trunk of the subjects were investigated and the conclusion was there was no change in gait patterns up to a load of 35 kg. Charteris (1998) found that stride frequency did not change with loads less than 50% body mass for males and 40% for females when the load was carried on the trunk. Martin and Nelson (1986) furthered these findings with a study that compared the gait pattern changes between men and women under various load conditions. Men and women were studied in five levels of military gear. Conclusions coincided with earlier findings that stride length did not differ significantly in the male subjects with increasing load. The female subjects, however, did show a consistent decrease in stride length as load increased. The females demonstrated shorter stride lengths during all conditions as compared to the male subjects. In addition, the females also had higher stride frequencies. This was thought to be due to the average limb length of females being shorter than that of males; however, this was not measured in their study. Martin and Nelson (1986) found that it was not the feet to ground contact time that was affected by load, but the swing time. Both males and females showed a decrease in swing time with increasing load. However, the magnitude of the decrease was greater in the female subjects, showing that they were more sensitive to load increases. Generally stride length and swing time decreased while stride frequency and double support time were increased with higher load. These changes were significant only in the female subjects. The researchers sited two main factors for the differences; females carried a greater relative load than the males and females have generally shorter limb lengths. The loads relative to body mass for the female subjects ranged from 1% to 60%. It is unclear at which load the gait changes obtained significance. In addition, Martin and Nelson stated that a portion of the gait pattern differences in females could be attributed to their smaller stature; there were no anthropometric measurements taken of the subjects to substantiate this conclusion. Cavanagh and William (1982) did take anthropometric measurements of their male subjects. They found that leg length, pelvic width, and foot length had greater correlations (-0.55 to –0.68) to running economy than did running mechanical variables.

Wagenaar (2002) explained this change in gait pattern with increasing speed and load. He found that at high walking speeds under increased load, hip excursion increases, but pelvic rotation decreases to a greater degree. This causes a shorter stride length and a resultant increase in stride frequency. Holt (2002) furthered this conclusion by suggesting that the torque of the upper body decreases under load. This inhibits the forward movement of the swing leg, decreasing the pelvic rotation, and thus shortening stride length. It is unclear, however, at which load or speed this becomes significant.

Hobbling Effect

Duggan (1988) studied the effect of multiple layers of clothing on energy cost in 12 male subjects from the British Army. Under four testing conditions with multiple layers of clothing, it was found that the increase in energy cost could not be fully explained by the increase in the weight of clothing. It was determined that multiple layers caused "a hobbling effect". The hobbling effect serves to increase energy cost beyond the corresponding weight increase of the layers. Each layer increases VO_2 by 3-4%. This could be due to increased binding of joints, whereby joint mobility is restricted. Also, there is friction between the layers of clothing during movement that would increase resistance for the subject. Hobbling impacts the proposed study as there will be three layers on the upper body, one layer on the lower body, and a duty belt around the waist.

A similar effect was found when adding mass to running subjects. Martin (1985) and Myers and Steudel (1985) found that when mass was added to the trunk area, there was a 1% increase in the absolute cost of running per kilogram of added mass. This value increased to 3.5% when the mass was added to the thighs and 7% when mass was added to the feet. This increase occurs in addition to what is seen when factoring in the weight increase alone. There was no mention as to whether there was a difference in percentages between the genders.

In this study, the majority of the mass added will be around the trunk. The average mass of the PPE in our pilot subjects was 7.8 kg. According to the research noted above, this would correlate to an increase of approximately 7.8% to the absolute cost of running. It is unclear whether this would also include walking.

Dual-Energy X-Ray Absorptiometry (DEXA)

Dual-energy x-ray absorptiometry (DEXA) utilizes a three-compartment model that quantifies fat, bone, and fat free soft tissue. It replaces other accurate but expensive or laborious methods such as neuron activation analysis or total body potassium calculations.

DEXA is non-invasive and scans the body with a low radiation X-ray. The body composition scans take approximately five minutes with a radiation dose equal to the amount that individuals are exposed to on a daily basis. Although DEXA is considered one of the most accurate tests for body composition currently available, there have been some conflicting reports on its validity. Aloia et al. (1994) tested the body compositions of 165 women using five methods and found that DEXA underestimated fat free mass and overestimated fat mass. It was determined that fat distribution played a major role in this variation in that, as fatness increases, the accuracy of DEXA decreases. This finding was supported in early research by Kohrt (1998), who found that DEXA underestimated fat mass in subjects with a large amount of torso fat distribution. The research determined that the problem was due to software difficulties and once corrected, DEXA no longer showed this problem. Kohrt concluded that DEXA was more accurate than hydrodensitometry in body composition assessment. Research by Svendsen et al. (1993) supported the accuracy of DEXA. By scanning seven live pigs then slaughtering and dissecting them, they found no significant difference between the DEXA estimates and the actual weights of soft tissue fat free mass and fat mass. Due to its availability and accuracy, DEXA was used to assess body composition in this study.

The lab technicians that performed the DEXA scans for this study, Wilkinson and McCargar, conducted an evaluation of the University of Alberta DEXA machine in 2004. They took seven males and 27 females and performed two scans on each subject within a one-week period. They found that the DEXA system had coefficients of variation (CV) of 1.5 g for fat and 0.6 g for lean mass. These researchers reported that the University of Alberta equipment was as reliable and precise as other systems reported in the literature.

Conclusion

From reviewing the literature, it is clear that police work involves maximal or near maximal physical exertion at unpredictable and sporadic times. While it has been well supported that physical fitness is very important in order to protect officers, co-workers, and the public, the lack of research in this area makes it difficult to determine what level of physical fitness is needed and how to best test for this.

The majority of the research in the police or law enforcement field centers around descriptive studies with the primary focus being on describing the duties, fitness levels, and psychological profiles of officers. There is an apparent absence of literature about the effects of police equipment on work capacity. As well, in studies that involve officers, the majority of subjects are male. The police field is a male dominated area and therefore it is more difficult to recruit a large sample of female officers for research. However, this creates problems when trying to generalize the results of studies to apply to all officers, including females. While the lack of research on law enforcement is staggering, this study will attempt to address one aspect of police work, the impact of police protective equipment on exercise capacity in female officers.

Chapter Three

Methods and Procedures

Research Design:

This study used a randomized crossover design. The study protocol consisted of three graded exercise treadmill tests. Each subject performed a practice test in order to familiarize herself with the protocol. Half the subjects performed the practice test in physical training equipment (PTE) and the other half in police protective equipment (PPE). This data was used to determine the reliability of the testing procedures. The subjects were then randomly assigned to the experimental testing protocol, which consisted of one test in each condition.

Subjects:

This study utilized 30 female police officers from the Edmonton Police Service (EPS). A recruitment letter was sent via interdepartmental email to every female police officer asking for their voluntary assistance. Each subject completed a Physical Activity Readiness Questionnaire (PAR-Q) to screen for health problems. There were no women with positive PAR-Q responses so none were referred to a physician. Any with unresolved health problems would have been excluded from the study. In addition, resting heart rate and blood pressure was taken prior to any testing. If the values exceeded 100 bpm or 144/94 mmHg (CSEP, 1998), subjects would have been referred to a physician to determine on an individual basis if they should have been excluded from the study. This did not occur with any of the subjects. Subjects over the age of 40 years were asked to obtain a note from their family physician ensuring of their good health and physical capability to participate in this type of research. There were two subjects who were required to do this.

Pregnant females were excluded from the study for safety reasons. The DEXA could not be performed on pregnant females and maximal exercise tests should not be done. One subject tested positive during the mandatory DEXA pregnancy test and she withdrew from the study.

Ethical Considerations:

Due to the military nature of police departments, the voluntary participation of each officer was confirmed by asking each subject in person. Only officers being tested were permitted in the testing area. As subjects were not tested in Edmonton Police facilities, any ethical concerns about supervisory involvement or breaching their personal information was alleviated. Individual results were not released to anyone except the participants. Each subject provided written informed consent. Review and approval of this study was obtained through the Faculty of Physical Education and Recreation Ethics Board (REB) of the University of Alberta.

Subjects signed the consent form found in Appendix D prior to any testing.

Procedures:

This study was conducted at the University of Alberta.

The weights of all subjects, with and without police equipment, were recorded on each day of testing, while heights were recorded on the first day.

Officers were not scheduled for testing during a period of midnight shifts in order to reduce variability due to lack of sleep. The researchers also attempted to schedule the subjects for the same testing time on each day and were successful within approximately two hours.

Subjects were given a list of instructions (Appendix D) that addressed food and alcohol consumption during the 24 hours prior to each test.

While there was some variation in the weight of PPE for each subject, the equipment was standardized to the greatest possible extent. The Kevlar® vest included a trauma plate, while the duty belt included standard operational equipment as follows: leather belt, two sets of handcuffs, radio and leather pouch, Glock® handgun, taser, extra magazine, Oleoresin Capsicum (OC) spray, 21" retractable baton, and flashlight. Police issue full Danner® boot, in addition to the regular summer issue duty uniform were worn by all subjects. Photos of the equipment used can be found on the following pages.

Plate 1: Female officer in the police protective ensemble (PPE)

Plate 2: Female officer in the police protective ensemble (PPE)

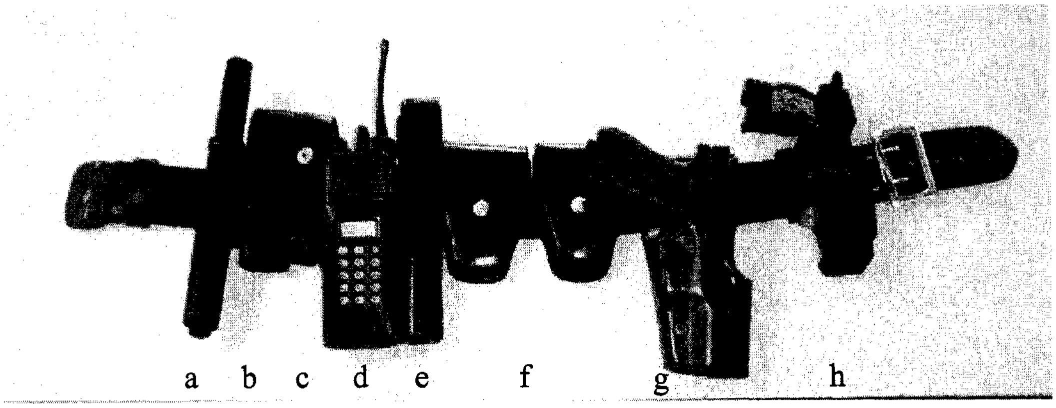


Plate 3: Duty belt, which includes:

a. 21" retractable baton
b. Extra magazine with 15 rounds
c. Oleoresin Capsicum (OC) spray
d. Radio and leather pouch
e. Flashlight
f. 2 sets of handcuffs
g. Glock handgun
h. Taser

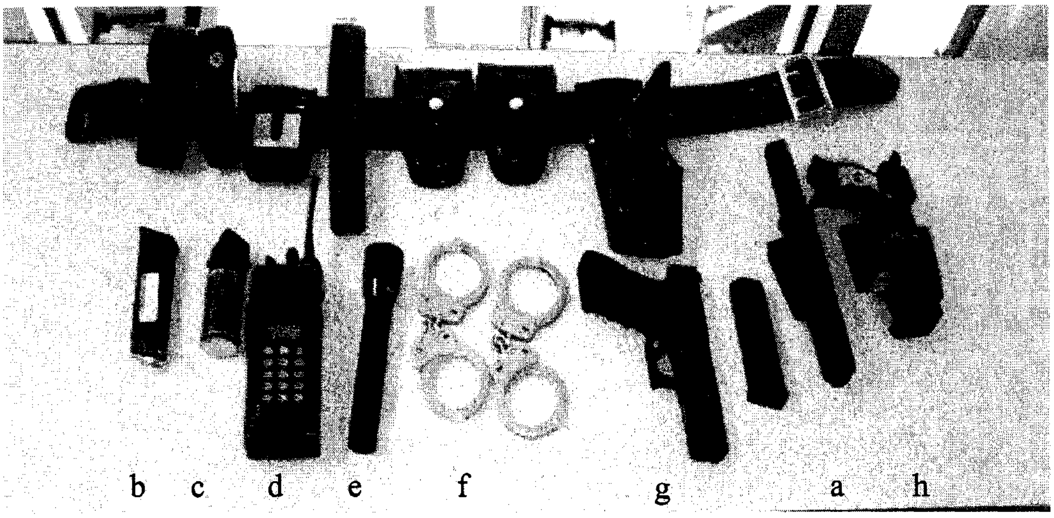
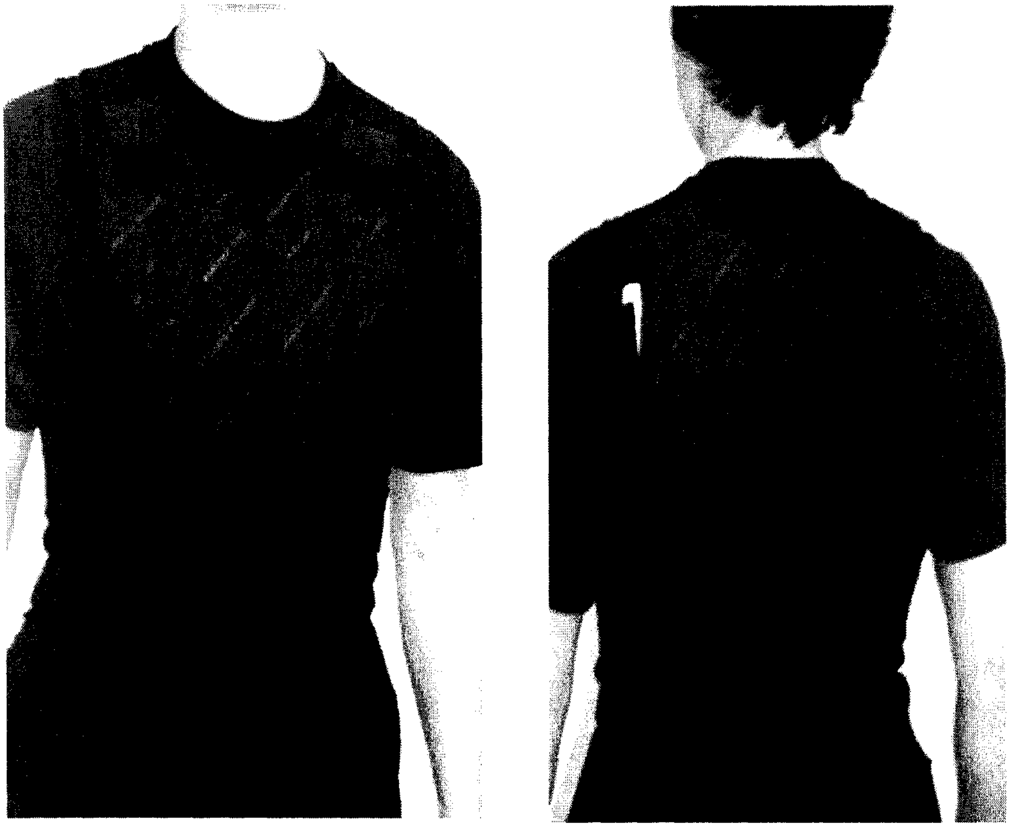


Plate 4: Duty belt with accouchements taken out, using the above legend.



Plates 5 and 6: Front and back view of the Kevlar® vest

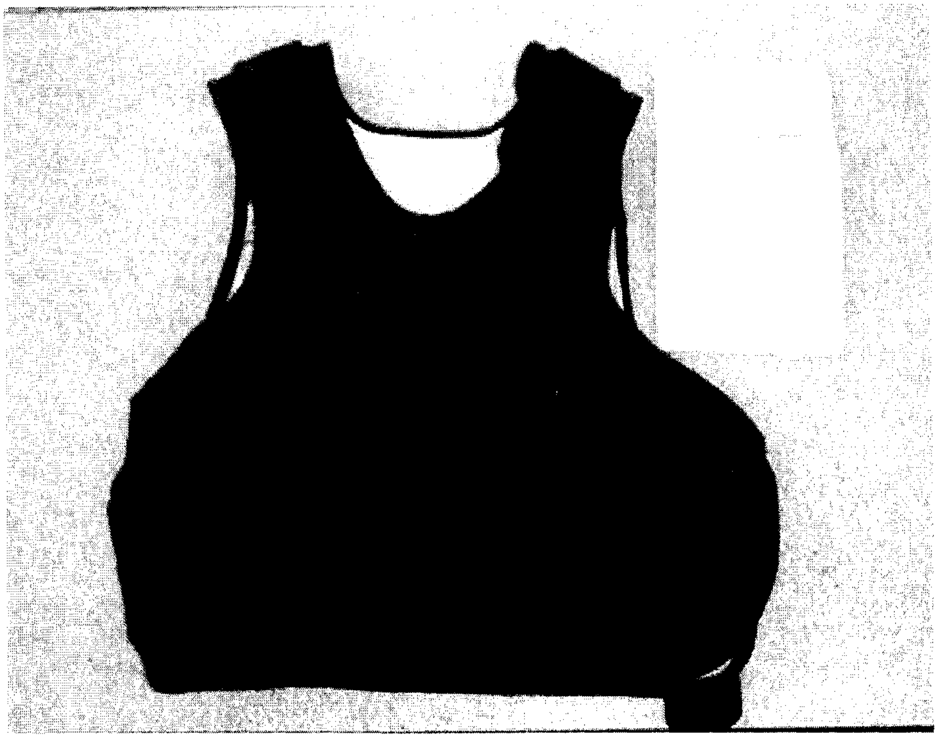


Plate 7: Kevlar® vest with trauma plate removed

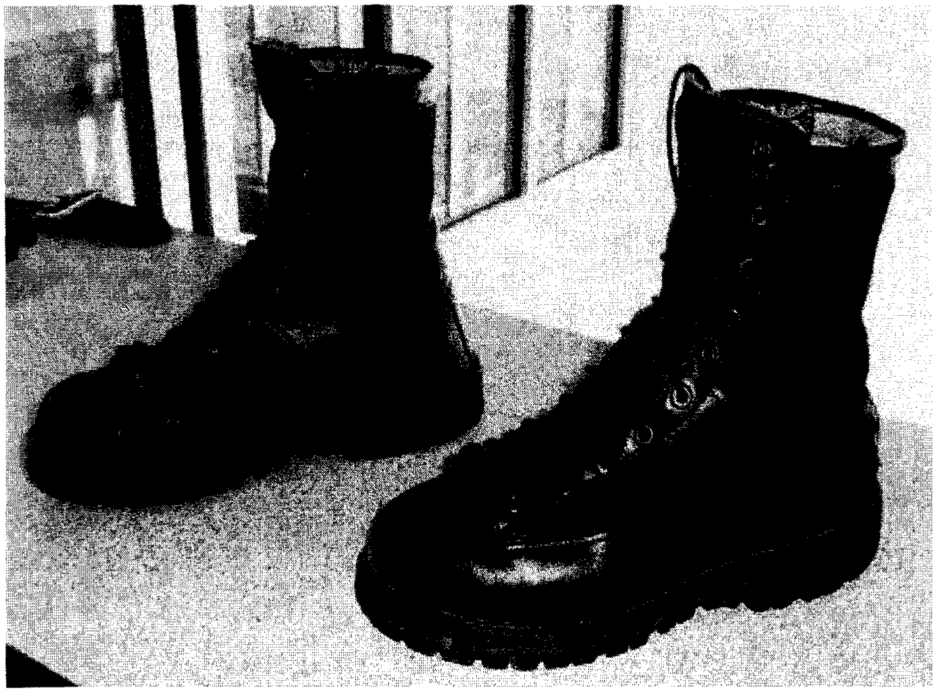


Plate 8: Danner® boots

On the first day, subjects were given the Letter of Information, Informed Consent and Par-Q. Additional questions were asked to determine prior experience with VO_{2max} tests, any outstanding musculoskeletal injuries and asthma problems. Resting blood pressure and heart rate were then taken. None of the subjects were excluded based on these factors.

On the first day of testing in police gear, subjects completed the lung function tests in both conditions so as to reduce day-to-day variability. The program used was the Office Medic Spirometry System, Version 1.06, Medical Graphics Corporation. The two tests performed were the flow volume loop and the maximal voluntary ventilation (MVV). Subjects performed a minimum of three trials for the flow volume loop and MVV in each condition with tests being repeated until two results had a difference of 5% or less. The tests were randomized according to condition with half the group completing the tests first in gym clothing then in police gear, while the other half tested in police gear first. The mouthpiece was changed between conditions in order to avoid saturation.

All data from the treadmill tests was collected using the same Truemax Metabolic cart. It was calibrated fully according to the manufacturer's guidelines prior to testing each day. The volume calibration was accepted within the range of 2970-3030 ml using a 3 L syringe. Gas calibrations were accepted with a 0.1% source of error. The gas calibration was repeated 5-8 times prior to the first test of the day as it was found that this practice resulted in less drift during testing. Gas calibration was repeated between the submaximal and maximal tests for each subject and was checked after each test.

The treadmill grade was calibrated once per week by utilizing a one-meter section of the treadmill at the point that it intersected with the floor. For a 5% grade, the rise should have been 5.2 cm while for a 10% grade the rise should have been 10.5 cm. It was found that the grade was consistently 0.5% lower and so to compensate for that, the settings were raised by 0.5%. The speed at 3.5 mph was also checked weekly. The belt length was 4.46 m. The expected revolutions per minute were calculated by taking the speed required, times the conversion factor of 26.82 m·min^{-1}/mph then divided by the length of the belt. It was found that the treadmill was very reliable at 3.5 mph but became unreliable at speeds above that. To address that difficulty, the revolutions per minute were taken as close as possible to VO_{2peak} while the subjects were performing their maximal tests. A regression equation of $y = 3.078 + 6.044X$ was found for speed and rpm which was used to calculate the speeds of the subjects at VO_{2peak}. Power was calculated according to the formula: PO = (weight in kg) (speed in mph)(grade/100)(26.82) / 6.12. Power was expressed in watts.

The protocol for the treadmill tests are shown in Tables 6 and 7 was consistent for all trials.

Table 6

Submaximal treadmill test for both conditions.

Test Stage	**Test Time (minutes)**	**Speed (m·min^{-1}/mph)**		**Grade (%)**
1 (Warm Up)	1-4	94	3.5	1
2	5-8	94	3.5	3
3	9-12	94	3.5	5
4	13-16	94	3.5	7
(Cool Down)	17-18	67	2.5	0

Between the submaximal test and the maximal test, there was a five minute break in which the subject was taken off the treadmill. Subjects were allowed to drink water during this break if they chose to. New mouthpieces were fitted to the headgear prior to resuming testing and a gas calibration was performed on the metabolic cart.

The steadystate criteria used was a VO_2 change of <50 ml·min^{-1} (Lang, P et al, 1992).

Table 7

Maximal treadmill test for both conditions.

Test Stage	**Test Time (minutes)**	**Speed (m·min^{-1}/mph)**		**Grade (%)**
1	1	94	3.5	0
2	2	94	3.5	4
3	3	94	3.5	6
4	4	94	3.5	8
5	5	107	4	8
6	6	120	4.5	8
7	7	134	5	8
8	8	148	5.5	8
	Continued until volitional fatigue			
(Cool Down)	1-3	67	2.5	0

The data sheets, are located in Appendix E.

The criteria that was used to determine if VO_{2max} was reached was:

- VO_2 readings do not change with increase workload. (<150 ml/min) (Heyward, 1998).

In the absence of a plateau or in addition to it, the following criteria were also used:

- respiratory exchange ratio greater than 1.15 (Stickland et al. 2000)
- too exhausted to continue. (Stickland et al, 2000)
- Rate of Perceived Exertion (RPE) (Borg, 1982) greater than 17 using the original Borg scale (Heyward, 1998).

As few subjects were able to meet the above criteria, particularly in uniform, VO_{2peak} (this was the highest VO_2 observed during the maximal test) was used for analysis.

In the third minute of each submaximal workload, stride frequency was counted to determine if stride length was altered between the two conditions.

During the maximal portion of the treadmill test, I recorded when each subject began to run and their total exercise time.

Each treadmill test was done on separate days with at least 24 hours separating each test. Subjects were asked to comply with a list of instructions (Appendix D) for the 24 hours prior to each test. Tests were scheduled at approximately the same time of day. Each subject completed her tests within a two-week window with the exception of one. In that case, the final tests were completed in three weeks.

Within two weeks of completion of the treadmill tests, a full body DEXA scan was conducted. The time commitment for the scan was approximately 30 minutes and was done at the Human Nutrition Research Centre at the University of Alberta.

Statistical Analysis:

The data was analyzed using the Statview program.

Paired t-tests were used to analyze the variables at VO_{2peak}. They were also used for variables such as total maximal exercise times. The submaximal data was analyzed first by repeated measures of ANOVA and then by a post hoc Tukey test, when significant F ratios were obtained. Simple regression was used to compare variables against VO_{2peak}, $VO_{2peak\text{-}diff}$ and age. Significance was set at $P \leq 0.05$. Descriptive results were presented as mean ± SD.

Chapter Four

Results

Subjects:

Thirty female volunteers from the Edmonton Police Service (EPS) were studied. The demographics of this group are displayed in Table 8. Thirty-three subjects initially began the study but three withdrew due to injuries unrelated to this study and pregnancy. The ranks of the officers who volunteered included 25 constables, two detectives, two sergeants and one staff sergeant.

Table 8

Characteristics of female police officer volunteers (n=30)

	Average	SD	Minimum	Maximum
Age (years)	31.8	5.5	22.2	43.0
Height (cm)	167.5	6.9	152.9	179.8
Weight (kg)	64.3	6.6	50.7	82.8
Years of Service	6.4	5.4	0.6	23.7

Each subject underwent a DEXA scan that tested for lean and fat mass. Those results are displayed in Table 9.

Table 9

Body composition results from the DEXA scan of the female police officer volunteers (n=30)

	Average	SD	Minimum	Maximum
% body fat	26.1	5.3	17.4	39.3
Body fat Z-score	-0.5	0.6	-1.8	1.0
Lean mass(kg)	45.5	5.8	34.5	65.6
% lean mass	70.7	4.9	58.4	79.3

During the DEXA scan, tibia and femur length were also measured. These results are in Table F-1.

Police Protective Equipment (PPE):

Despite standardizing the PPE used by each subject, there was some variation in the weight between subjects. The average weight was 8.5 ± 0.6 kg with a minimum of 7.3 kg and a maximum of 9.9 kg. When the percentage of gear weight to body weight was calculated, the average was 13.3 ± 1.3 % with a minimum of 10.9% and a maximum of 15.7%.

Test trials vs. Experimental trials:

Each subject performed one test trial either in PPE or PTE. There were 14 subjects who performed their test trial in PPE while 16 performed their trial in PTE. The variation was due to the three subjects who dropped out. There was no significant difference in VO_{2peak} between the test and experimental trials in either PTE or PPE. The trial and experimental test results for VO_{2peak} are displayed in Tables F2-3.

Power Output:

The power output results are displayed in Figure 1 with the raw data in Table F-5.

The submaximal test results revealed that there were significant differences between conditions ($p < 0.0002$). This could be attributed to the weight of the police equipment as it was, on average, 13% of subjects' body weight. Mean power output was consistently 13% higher in PPE than in PTE.

There was no difference in power outputs at VO_{2peak} ($p = 0.16$). Subjects were able to achieve the same power output in police equipment as they did in shorts and t-shirt. However, the speeds attained at VO_{2peak} were different. In shorts, subjects were able to run an average of 1.83 minutes longer with a speed of 160.9 m·min^{-1} (6 mph) as compared to PPE in which the subjects' average speed was 147.5 m·min^{-1} (5.5 mph).

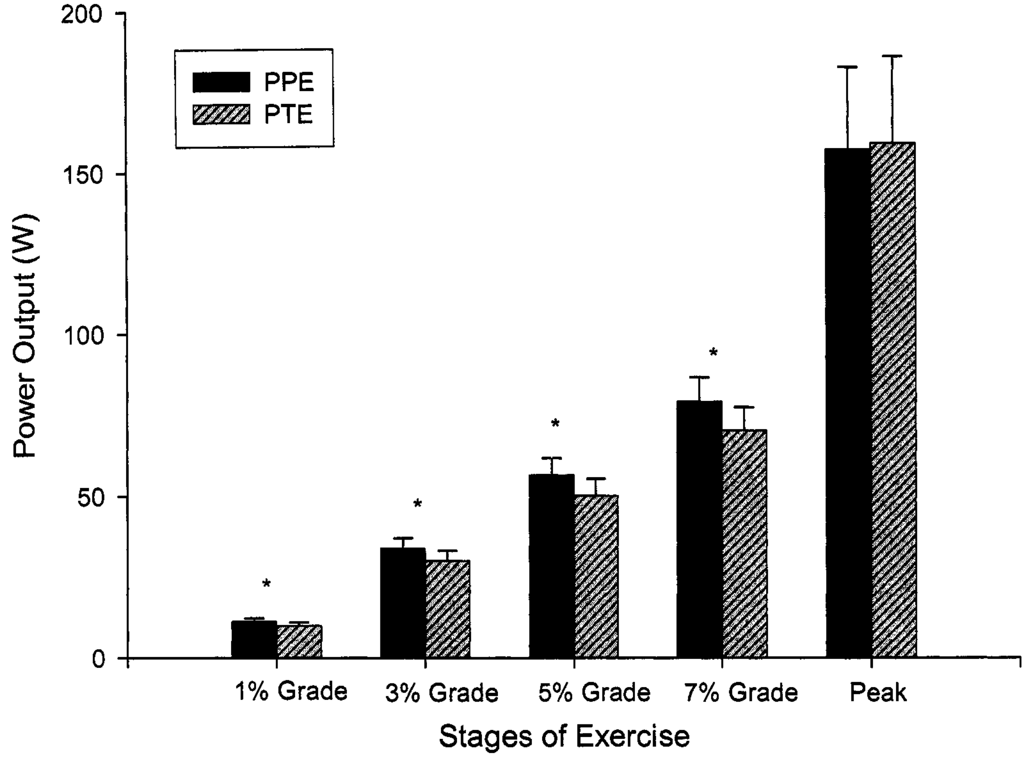


Figure 1: Power output for submaximal (Stages 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n=29) in PTE and PPE conditions, * $p \leq 0.05$ between conditions.

Absolute VO$_2$:

The results for VO$_2$, expressed as L·min^{-1} are displayed in Figure 2 while the raw data can be located in Table F-12.

Absolute submaximal VO$_2$ showed a condition effect ($p < 0.0002$) with the police condition being 18-20% higher than the shorts condition.

There was a mean difference of .01 L·min^{-1} ($p = 0.49$) in VO_{2peak} between the two conditions so subjects were able to achieve the same VO_{2peak} in shorts as in police gear.

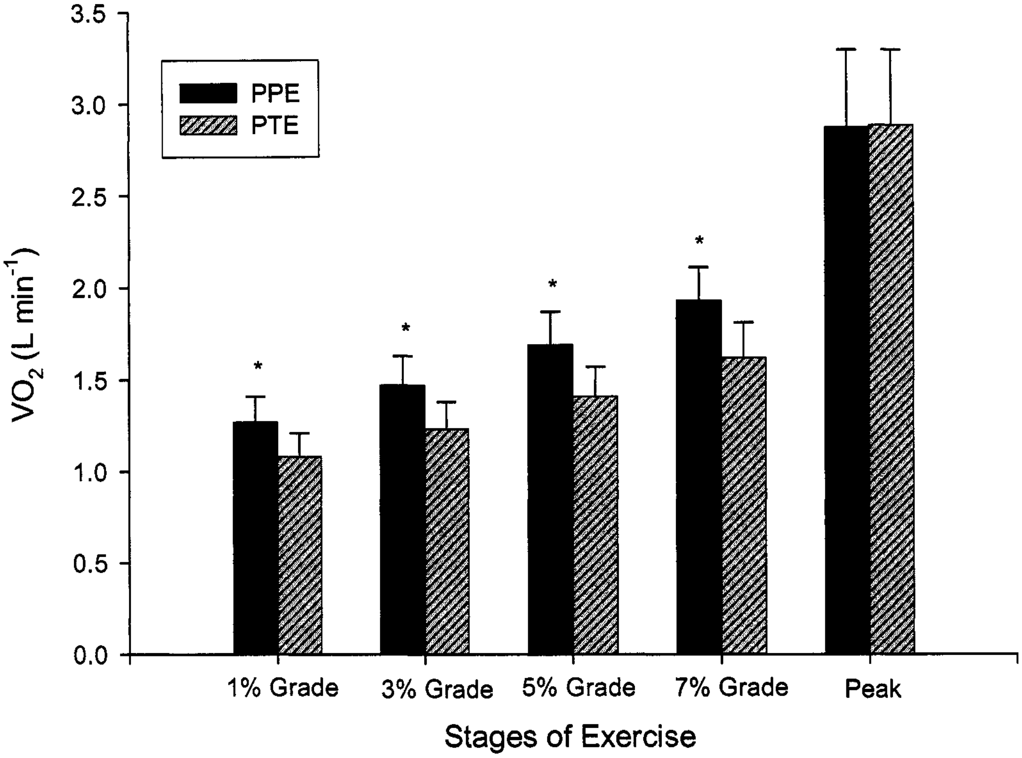


Figure 2: Absolute VO_2 for submaximal (Stages 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n=29) in PTE and PPE conditions, * $p \leq 0.05$ between conditions.

Relative VO_2:

The results for relative VO_2, expressed as ml·kg^{-1}·min^{-1}, are displayed in Figure 3 while the raw data is in Table F-11.

The PPE condition was calculated by factoring in the weight of the police equipment in addition to the subjects' weight.

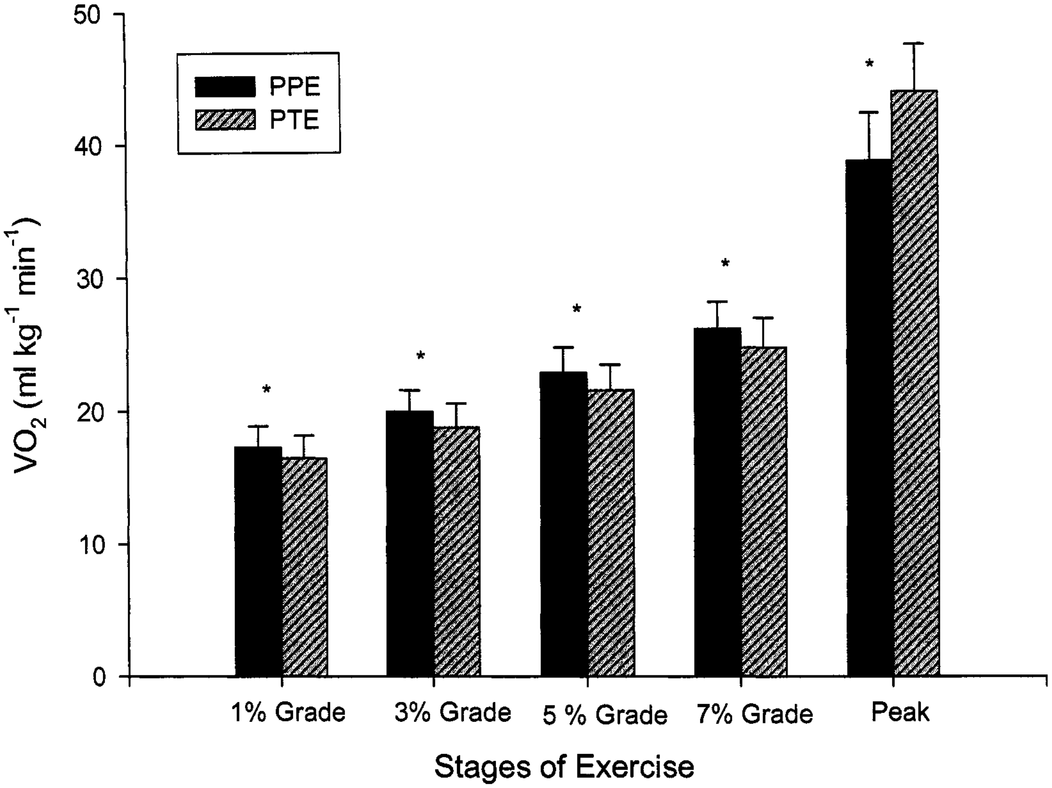


Figure 3: Relative VO_2 results for submaximal (Stages 1-4) and maximal (Stage 5) for female police officers (n=30, except stage 4 where n=29) in PPE and PTE, * $p \leq 0.05$ the two conditions.

The submaximal results revealed a 6% increase ($p < 0.0002$) in VO_2 in the police condition for all four stages except the first, which showed an increase of 5%.

For the VO_{2peak} results, a mean difference of 5.2 $ml \cdot kg^{-1} \cdot min^{-1}$ ($p < 0.0001$) was observed with PTE being higher than PPE, which correlates to a drop of 12%.

Ventilation:

The ventilation (VE) results are displayed in Figure 4 while the raw data can be located in Table F-7.

VE in the submaximal stages was 18-26% higher ($p < 0.0002$) in the police condition.

At VO_{2peak}, there was no difference ($p = 0.77$) so subjects were able to reach the same ventilation in both conditions.

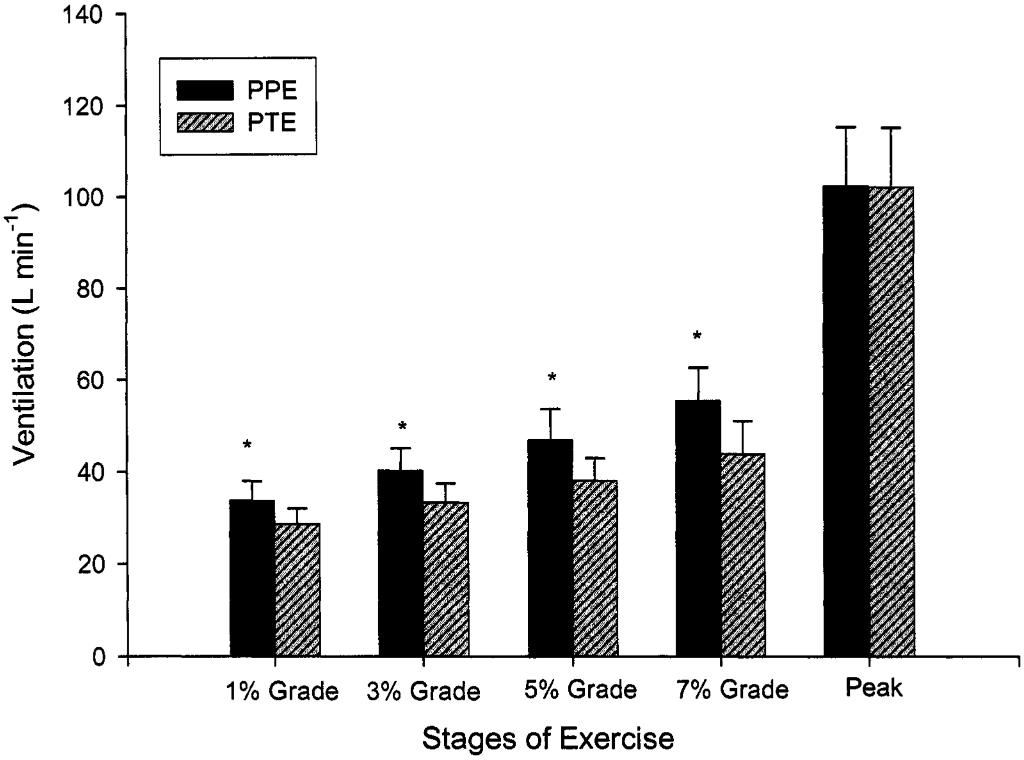


Figure 4: Ventilation for submaximal (Stages 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n=29) in PTE and PPE conditions, * $p \leq 0.05$ between conditions.

Breathing Frequency:

The breathing frequency [breaths per minute (bpm)] results are presented in Figure 5 while the raw data can be located in Table F-10.

As with ventilation, it was discovered that there were significant effects for the submaximal data ($p < 0.04$) with PPE higher by 8-14%.

Unlike ventilation however, the difference at VO_{2peak} was significant at 1.67 bpm ($p = 0.04$), which corresponds to a 4% increase in the police condition.

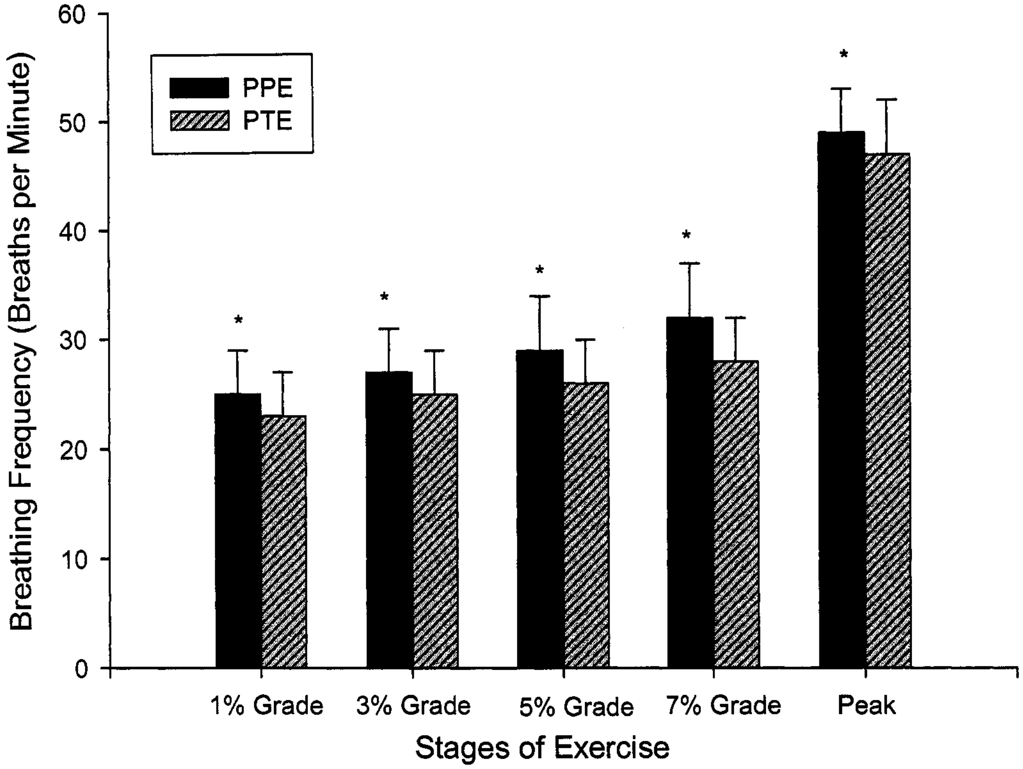


Figure 5: Breathing frequency for submaximal (Stages 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n=29) in PTE and PPE conditions, * $p \leq 0.05$ between conditions.

Tidal Volume:

Tidal volume results are found in Figure 6 while the raw data can be located in Table F-13.

As with ventilation and breathing frequency, there were significant increases (7-10%) in tidal volume for the submaximal stages ($p < 0.001$).

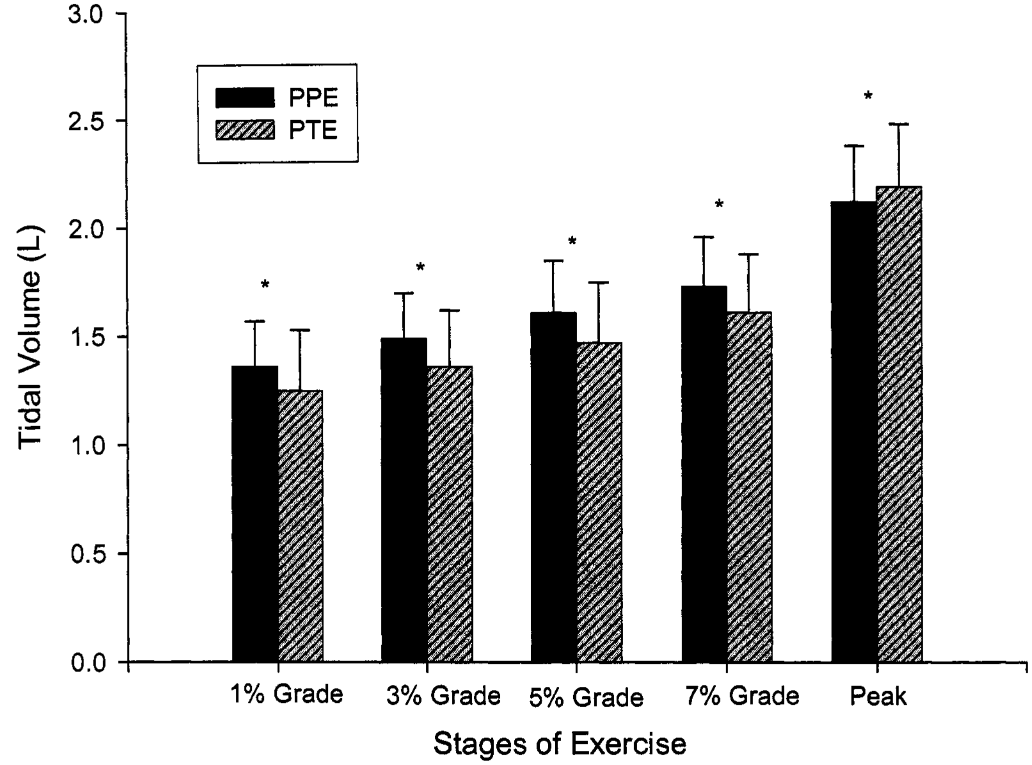


Figure 6: Tidal volume for submaximal (Stages 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n=29) in PTE and PPE conditions, * $p \leq 0.05$ between conditions.

However, the interesting finding was seen with the VO_{2peak} results. The difference was significant between the conditions with a value of 0.07 L ($p = 0.008$) with the police condition being 3% lower than the gym condition. While ventilation did not show a significant difference, both tidal volume and breathing frequency did. Tidal volume was lower at VO_{2peak} while breathing frequency was higher in the PPE condition.

Lung Function Tests:

Each subject completed two lung function tests, maximal volume ventilation (MVV) and a flow volume loop in both conditions. The raw data can be found in Table F-16.

The MVV tests revealed a mean difference of 1.81 L·min^{-1} ($p = 0.42$). However, the FVC results showed a mean difference of 0.2 L ($p = 0.01$), which was significant. In examining the FEV_1 results, the mean difference and p-value are the same as those in the FVC results.

Heart Rate, Rating of Perceived Exertion, RER and VCO_2:

Rating of perceived exertion, RER and VCO_2 all followed the same trend. The conditions during the submaximal workloads were significantly different from each other but were not at VO_{2peak}. The only difference in the trend for heart rate was that it was also significantly different at VO_{2peak} with the police condition being higher by 4% than the shorts condition. The raw data and graphs can be located in Tables F-6, 8, 9, 14 and Figures F-1 through 4.

Exercise Time and Run Start:

Run start and total exercise times are presented in Table F-15.

A paired t-test of the run start times revealed a mean difference of 0.1 minutes ($p = 0.50$). Total exercise times however, revealed a mean difference of 1.8 minutes ($p < 0.0001$). In PTE, the average total exercise time was 9.9 minutes with a speed of 160.5 m·min^{-1} while in PPE, the time was 8.1 minutes with the average speed of 133.8 m·min^{-1}.

Stride Frequency (Submaximal Data):

Stride frequency was recorded for the submaximal workloads only and can be found in Table F-4. There was no effect between the two conditions and no significant effect as grade increased.

Area Under the Graph (VO_{2peak}):

The area under the graph for VO_{2peak} for both conditions was calculated with the average PTE values of 19.59 L and 297.41 ml kg^{-1} and average PPE values of 16.47 L and 221.06 ml $^{-1}$. This is a 19% difference for absolute VO_{2peak} and a 34% difference for relative VO_{2peak}.

Ratios of Variables:

The ratios of PPE/PTE of the variables investigated are presented in Tables 10 and 11. The ratios are simply a fraction of the results of PPE/PTE and show the differences according to the data collected.

Table 10

Variable comparisons expressed as PPE/PTE for female subjects (n=30)

Stages	**Ventilation**	**Tidal Volume**	**Breathing Frequency**	**VCO_2**	**Heart Rate**
1	1.18	1.09	1.09	1.21	1.10
2	1.20	1.10	1.08	1.23	1.14
3	1.23	1.10	1.12	1.24	1.16
4	1.26	1.07	1.14	1.25	1.14
5	1.00	0.97	1.04	1.00	1.04

Table 11

Variable comparisons expressed as PPE/PTE for female subjects (n=30)

Stages	RER	Relative VO_2	Absolute VO_2	Power Output	RPE
1	1.04	1.05	1.18	1.13	1.17
2	1.03	1.06	1.19	1.13	1.28
3	1.03	1.06	1.20	1.13	1.25
4	1.04	1.06	1.19	1.13	1.20
5	1.00	0.88	1.00	0.99	1.00

Regression Analysis:

The critical value for r for the following is 0.361 based on significance of 0.05 and a two-tailed test with 28 degrees of freedom. Regression was performed with the independent variables such as height and weight as predictors of VO_{2peak}.

Table 12

Regression analysis (r) with VO_{2peak} as the dependent variable

	PTE Absolute VO_{2peak}	PTE Relative VO_{2peak}	PPE Absolute VO_{2peak}	PPE Relative VO_{2peak}
Height	0.42*	0.08	0.52*	0.31
Weight	0.80*	0.12	0.77*	0.23
Gear Weight			0.32	0.00
% Gear/Body Weight			-0.61*	-0.24
Leg Length	0.25	-0.14	0.36	0.10
% Body Fat	-0.22	-0.35	-0.29	-0.45*
Body Fat Z-Score	-0.14	-0.29	-0.21	-0.38*
Lean Mass	0.79*	0.30	0.81*	0.44*
% Lean Mass	0.23	0.35	0.31	0.45*
Age	-0.28	-0.26	-0.30	-0.32

*$p<0.05$

As expected for absolute VO_{2peak} in physical training gear, the physiological variables of height, weight and lean mass were significant, Table 12. The larger the subject, the greater their muscle mass and thus the higher their VO_{2peak} should be.

However, when VO_{2peak} was expressed as a function of body weight, relative VO_{2peak}, then the significance was lost. For absolute VO_{2peak} in police gear, again height, weight and lean mass were significant but % gear/ body weight was also. This demonstrates that the weight of the police gear did factor into the performance on the maximal test. When expressed as relative VO_{2peak}, the factors that were significant were % body fat, body fat z-score, lean mass and % lean mass. The less body fat and the more lean mass one had, the better the performance on the police maximal test.

Table 13

Regression analysis (r) with $VO_{2peak\text{-}diff}$ as the dependent variable

	Absolute $VO_{2peak\text{-}diff}$	**Relative $VO_{2peak\text{-}diff}$**
Height	-0.53*	-0.61*
Weight	0.01	-0.27
Gear Weight	-0.37*	-0.49*
% Gear/Body	-0.28	-0.06
Leg Length	-0.53*	-0.62*
% Body Fat	0.37*	0.26
Body Fat Z-Score	0.35	0.22
Lean Mass	-0.20	-0.37*
% Lean Mass	-0.36	-0.26
Age	0.11	0.14
Rel VO_{2peak}	0.00	0.21
Abs VO_{2peak}	-0.02	-0.12

*$p<0.05$

Table 13 shows the regression analysis of $VO_{2peak\text{-}diff}$ as the dependent variables against the factors listing in the left column. The $VO_{2peak\text{-}diff}$ is the differences in absolute and relative VO_{2peak} between the two conditions. For absolute VO_{2peak}, height, gear weight, leg length and % body fat were significant. When expressed as relative VO_{2peak}, height, gear weight, leg length and lean mass showed significance. Taller subjects generally have longer legs, so these two factors express similar information. The factors that police officers can control however are % body fat and lean mass.

Table 14

Regression analysis (r) with age as the independent variable

	Age
Weight	-0.15
% Body Fat	0.22
Z-Score	-0.03
Lean Mass	-0.23
% Lean Mass	-0.20
Rel VO_{2peak}	-0.26
Abs VO_{2peak}	-0.28

*$p<0.05$

Table 14 displays the analysis of how age would be a predictor of the variables listed in the left column. With this subject group, age was not a significant predictor in any of the investigated variables.

Chapter Five

Discussion

The main purpose of the study was to investigate differences in the physiological variables associated with walking economy and VO_{2peak} when comparing exercise in police protective equipment (PPE) and physical training equipment (PTE) in female police officers volunteers. The major findings were that stature played a role in performance in the police equipment, ventilation was maintained even though tidal volume was reduced at VO_{2peak}, and that much of the differences seen in power output and VO_2 could be explained by the weight of the equipment and the "hobbling effect".

Subjects:

The subjects were healthy female volunteers from the Edmonton Police Service (EPS). The level of physical activity varied from sedentary to highly trained. Volunteers encompassed a wide range of years of service, ranks and ages, with two women aged 40 years or over. Also, there were two smokers who participated. The subjects seemed very highly motivated to perform their best and as they all performed the tests in their own equipment, a learning effect was avoided.

Results from the DEXA scans showed overall a very, lean group of women with their body fat z-score being below the average at –0.5 and a corresponding 26.1% body fat. Using traditional body composition tests such as underwater weighing or skin folds, the percent body fat recorded by this group would seem high. However, the DEXA scans measure not only subcutaneous body fat but also the internal fat such as that found around organs. The z-score was necessary to interpret these results. The average z-score of –0.5 showed that this group was below normal for body fat based on the data bank from the DEXA manufacturer. The reference group was American Caucasian women. There were no women of minority in this study so all women were compared to the appropriate reference group.

The officers involved in this study were representative of the Edmonton Police Service female population as seen in Table 15. As of July 2005, there were 232 females officers and a total of 1720 in Edmonton, giving a percentage of 13% of the membership. Of the female officers currently employed, 13% volunteered for this study.

Table 15

Comparison of study population to EPS female population

	Study Average	EPS Average	Study Range	EPS Range
Age (years)	31.8	34	22.2 – 43.0	21 - 54
Weight (kg)	64.3	66.1	50.7 – 82.8	45.4 – 95.2
Height (cm)	167.5	168.1	152.9 – 179.8	152.4 – 185.4

Power Output:

In an occupation such as police work, it is important to be able to maintain a high external power output when responding to critical incidents. While the subjects at VO_{2peak} were able to achieve the same power output in uniform as they did in gym strip, the type of work they were able to perform differed between the conditions. In police gear, subjects ran approximately 1.83 minutes less than in shorts and 16.8 $m \cdot min^{-1}$ (1.0 mph) slower. The finding that power output at VO_{2peak} was equal between conditions is somewhat misleading. Subjects had to expend extra energy in order to carry the weight of the police equipment and this prevented them from running as fast and decreased total exercise time during the treadmill tests. During the submaximal workloads power output in police gear was 13% higher than in shorts. This has implications for daily activities that police officers must perform, such as walking the beat and responding to routine calls for service. The amount of energy they must expend simply to wear the equipment necessary to perform their duties is significant. It is possible that external work decreases while in uniform because of the need to compensate for carrying the weight of the police equipment. This could also have implications on fatigue and injuries on the job.

Walking Economy:

Stride frequency and therefore stride length did not change with either intensity or condition. This is consistent with the studies by Pierrynowski (1981) and Charteris (1998). Pierrynowski (1981) concluded that there were no gait changes with loads up to 35 kg. Charteris (1998) found that stride frequency did not change with loads less than 40% body mass in females when load carriage was around the trunk. While the police gear did not affect stride frequency and length, it is unclear whether the biomechanics of walking and running were altered, as this was not investigated. Stride frequency data was not recorded during the VO_{2peak} test protocol and this would be an area for further research.

Submaximal VO_2 was used as the marker of walking economy. Absolute VO_2 in police gear was 18-20% higher than in gym clothes. As the weight of the equipment could account for about 13% of that, there is 6-8% of the change to be explained. This was close to the 5-6% difference observed in the relative VO_2 between conditions. This difference could be explained by the hobbling effect as will be discussed next.

The pattern of elevated results for the PPE condition was consistent for all the physiological responses that were investigated including VCO_2, RER, ventilation, breathing frequency, tidal volume and heart rate. This could be explained by the change in power output because even though the speed and grade of the treadmill did not change between conditions, each subject was carrying approximately 8.5 kg of police gear and thus were working harder. This was confirmed by the power output, as each stage in PPE was 13% higher than the same stage in PTE. This increase in power output was discernable by the subjects as RPE results were significantly higher in PPE than in PTE for all submaximal stages. It was interesting to note that while the changes in power output and VO_2 were about 13-20% higher in police gear, subjects rated the difficulty of tests, according to RPE, as 17-28% higher.

***Hobbling Effect*:**

A "hobbling effect" influenced physiological responses in the police condition during the submaximal workloads. As noted above, there is approximately a 6-8% change in VO_2 during submaximal exercise that needs to be explained. According to Duggan (1988), each layer increases VO_2 by 3-4% due to binding of the joints and friction between the layers. This is consistent with our findings. With the added vest, shirt and belt, we would expect an increase in VO_2 of 6-12%. Also, Martin (1985) and Myers and Steudel (1985) found that there was a 1% increase to the absolute VO_2 per kilogram of added weight to the trunk region. According to the results of these studies, there should be an additional increase in submaximal energy expenditure of 8.5%. The combination of these two types of hobbling effect gives an expected result if 14.5-20.5% increase in PPE, which was what was observed in this study.

VO_{2peak}:

As some of the subjects in uniform were unable to meet the criteria of VO_{2max}, particularly when in police gear, VO_{2peak} was used instead. As noted above, there was no difference in absolute VO_{2peak} but was a 12% difference in relative VO_{2peak} between conditions. This would suggest that the weight of the police equipment was the primary cause for the difference. The average weight of the police gear was 13% of the subjects' body weight and the average drop in VO_{2peak} during the police condition was 12%.

Comparisons are difficult, as much of the literature did not isolate the female VO_{2peak} data (Franke and Anderson, 1994) from the male data or studied males exclusively (Stamford et al, 1978; Wiles, 1986; Metivier et al, 1982; Wilmore and Davis, 1979; Klinzing, 1980; Pollock et al, 1978). Only two studies reported female data separately. Spitler et al (1987) included 3 female officers with the average VO_{2max} result of 41.5 $ml \cdot kg^{-1} \cdot min^{-1}$. Rhodes and Farenholtz (1992) included 25 women with average results of 39.0 $ml \cdot kg^{-1} \cdot min^{-1}$ or 2.5 $L \cdot min^{-1}$. This study saw average VO_{2peak} results of 43.0 $ml \cdot kg^{-1} \cdot min^{-1}$ and 2.82 $L \cdot min^{-1}$. The female officers involved in this study were more aerobically fit than in the previous published research.

There were no significant differences between the two conditions for the following variables: ventilation, VCO_2, RER, relative, absolute VO_{2peak}, power output and RPE. The variables that showed significant differences were: relative VO_2, tidal volume, breathing frequency and heart rate.

It is important to note that while subjects were able to reach the same power output in both conditions, the time run in police gear was significantly shorter with a difference of 1.83 minutes. The average speed attained on the treadmill was 20% slower in police gear (160.5 $m \cdot min^{-1}$ for PTE and 133.8 $m \cdot min^{-1}$ for PPE). As well, the area under the graph shows that the amount of aerobic work complete was 19% lower for absolute VO_{2peak} and 34 % lower for relative VO_{2peak} while in uniform. This clearly shows that police protective equipment impacts maximal exercise performance and quickens the time to exhaustion, a finding with important implications for aspects of police work such as foot chases.

Breathing Responses:

As stated above, there was no significant difference in ventilation at peak exercise. However, there were significant differences in tidal volume and breathing frequency. Tidal volume was lower in the police condition while breathing frequency was higher. This suggests that the police equipment, particularly the vest and belt, inhibited subjects from breathing as deeply at VO_{2peak}. However, they were able to compensate for this by increasing their breathing frequency in order to maintain the high ventilation required at VO_{2peak}.

This was consistent with the lung function tests. Maximal voluntary ventilation (MVV) did not differ between the conditions, while FVC and FEV_1 was significantly lower in PPE than in PTE. Lower lung volume as seen by decreased FVC is most likely responsible for lower FEV_1. It is unclear whether the belt or the vest was the main contributor to this result.

These findings are consistent with a published study that investigated the effects of chest strapping on respiration (O'Donnell et al, 2000). Researchers discovered that while vital capacity was reduced by 60%, peak ventilation did not change. Subjects also gave feedback via the Borg scale with elevated responses during chest strapping.

Regression Analysis:

Regression analysis was done using VO_{2peak} as the dependent variable. For absolute VO_{2peak} in both conditions, height, weight and lean mass were significant. These variables were also significant in the PPE condition but also % gear/ body weight was found to be significant as well. Logically, the larger in stature and muscle mass one is, the more of an oxygen demand one would have. These factors were not significant for relative VO_{2peak}. In PTE, there were no significant factors in this study that were predictive of relative VO_{2peak}. In the police condition, % body fat, body fat z-score, lean mass and % lean mass became significant for relative VO_{2peak}. This indicates that the less body fat and more muscle mass one has, the better one would be expected to perform on the maximal test in police equipment.

When considering $VO_{2peak\text{-}diff}$ as the dependent variable, the three variables of height, leg length and gear weight were significant for both absolute and relative tests in both conditions. Taller subjects would be expected to demonstrate less of an impact from the police equipment than shorter officers. Also, the less the equipments' weight, the lower the expected difference between the conditions. For absolute $VO_{2peak\text{-}diff}$, % body fat was significant, while for relative $VO_{2peak\text{-}diff}$ lean mass was significant. This suggests that controllable factors such as fat and muscle mass could impact the effects of police gear.

Contrary to the second hypothesis, aerobic fitness was not a significant predictor of either absolute or relative $VO_{2peak\text{-}diff}$.

Gear weight was a significant predictor for both absolute and relative $VO_{2peak\text{-}diff}$. This has implications for companies that design police equipment. New materials and equipment that would lighten the weight for officers to carry would have a tremendous impact on daily and critical incident performance.

Regression Analysis with Age:

Although this was not a primary focus of this project, it was interesting to analyze the data with respect to age. Regression analysis was run with age being the independent variable to determine if age was a predictor of weight, % body fat, Z-score (body fat), lean mass, % lean mass, VO_{2peak} and $VO_{2peak\text{-}diff}$. In this group of 30 female police officers, the older officers were not significantly different from the younger ones in respect to fitness or physiological variables. This is in contrast to published literature suggesting that as officers' age, fitness decreases and body fat increases. As this was a volunteer group and not a random sample of the population, this finding is not surprising. It was expected that the more fit female members would volunteer for a study of this nature and that more sedentary members would not. Therefore, no conclusions could be extrapolated towards the whole population based on this quite fit group of individuals.

Implications:

With the exception of Ontario's PREP, no police applicant test requires any additional weight to be added to individuals. The most commonly used test in Canada, the PARE, which is used not only by the RCMP, but also by numerous other departments, has applicants run the test in shorts and t-shirts. The PREP requires 3-4 kg of weight be strapped around applicants' waists. This is less than half of what is reported in this study on female officers. When looking at the entire population of males and females, the average weight of the PPE will increase.

The findings in this study have implications for testing. To increase job-related validity, some additional weight needs to be added as a requirement of any PAT. The problem arises with trying to determine how much weight. More research in this area needs to be conducted in order to have a more complete picture of what males and females carry. My suggestion based on this study is two-fold. In order to avoid adverse impact, the amount of added weight should be a percentage of the applicant's body weight, as in this example, 13%. This number could change depending upon further research. In addition, the minimum weight of the equipment needs to be determined so that the smallest applicants are still tasked with a reasonable replication of the on-job demands.

Conclusion:

The ventilatory responses were an interesting finding in this study. Subjects were able to compensate for a reduction in tidal volume by increasing breathing frequency in order to maintain ventilation. Changes in submaximal VO_2 appears to be explained by the "hobbling effect". For peak exercise, it was interesting to note that stature was an uncontrollable factor that could partially mitigate the effects of the police gear at peak exercise. Two controllable factors that could also help reduce the effects were fat and muscle mass. This could impact how officers physically train for the rigors of the job. The more muscle mass and less fat mass one carries, the better one's performance in a critical incident.

Police agencies should have an interest in the submaximal and maximal results of this study. The fact that daily energy expenditure increases by 18-20% while maximal VO_2 decreases by 12% shows a significant impact of the police equipment in daily activities and some critical incidents. Not only does this support the recommendation made by the International Association for Chiefs of Police for fitness programs for all officers, it also supports the Commission of Accreditation for Law Enforcement Agencies requirement for physical fitness standards for applicants and incumbents. The results of this study should be considered in setting the minimum standards.

Affiliated police supply companies should also be interested in these findings as they demonstrate that not only the weight of the PPE, but also the “hobbling effect” is important. If equipment can be designed so as to reduce the overall weight and the binding that is associated with the layers, then officers would not face the degree of handicapping they currently work with. Protective vests by design are restrictive, however, supply companies can investigate the ways to reduce the inhibition of the chest wall.

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Appendix A

Definitions:

<u>*Adverse impact*</u>: Adverse impact occurs when less than eighty percent of a protected class passes at a set standard established at the pass rate of a majority group (Collingwood, 1995). For example, if less than eighty percent of female applicants are able to pass a physical test that has the passing standard set based on male data an adverse impact exists.

<u>*Bona Fide Occupational Requirement (BFOR)*</u>: are conditions of employment necessary for "the safe, efficient and reliable performance of the job" (Gledhill et al, 2001).

<u>*Dual Energy X-Ray Absorptiometry (DEXA)*</u>: is a test that uses low dose x-rays in order to distinguish between bone and soft tissue. It provides an assessment of bone density, lean tissue mass and fat mass.

<u>*Physical fitness*</u>: "the ability to carry out daily tasks with alertness and vigor, without undue fatigue, and with enough reserve to meet emergencies or to enjoy leisure time pursuits" (Mosby's Medical and Nursing Dictionary, 1986).

$\underline{VO_{2max}}$: "the maximal rate at which oxygen can be consumed" (Foss and Keteyian, 1998)

<u>*Walking Economy*</u>: "aerobic demand (VO_2) of submaximal" walking (Morgan and Craib, 1992). It is also called 'efficiency' in the literature, which is defined as "the relationship between work done and energy expended" (Daniels, 1985). In this study, the term 'walking economy' will be used.

Hobbling Effect: A "disproportionate rise in energy cost . . . when multilayered protective clothing ensembles are worn" (Duggan, 1988). This is due to binding of the joints and friction between the layers.

Appendix B

Pilot Work

In March and August 2003, four subjects were tested to obtain pilot data. Two subjects were civilians; one male and one female, while two subjects were female police officers. The exercise protocol for determining economy included four progressive stages that allowed adequate duration for the physiological variables to approach steady state. Subsequently, the speed was increased by 13.4 m·min^{-1} (0.5 mph) each minute until the subject was too exhausted to continue. The loading protocol is shown in Table 6.

Table B-1

Pilot study protocol

Test Stage	Test Time (minutes)	Speed (m·min^{-1} /mph)		Grade (%)
1 (Warm Up)	1-3	94	3.5	0
2	4-7	107.3	4.0	2
3	8-11	107.3	4.0	4
4	12-15	107.3	4.0	6
5	16-19	107.3	4.0	8
6	20	120.7	4.5	8
7	21	134.1	5.0	8
8	22	147.5	5.5	8
9	23	160.9	6.0	8

The results for all the subjects followed the same trend as subject one which is depicted in Figure 1.

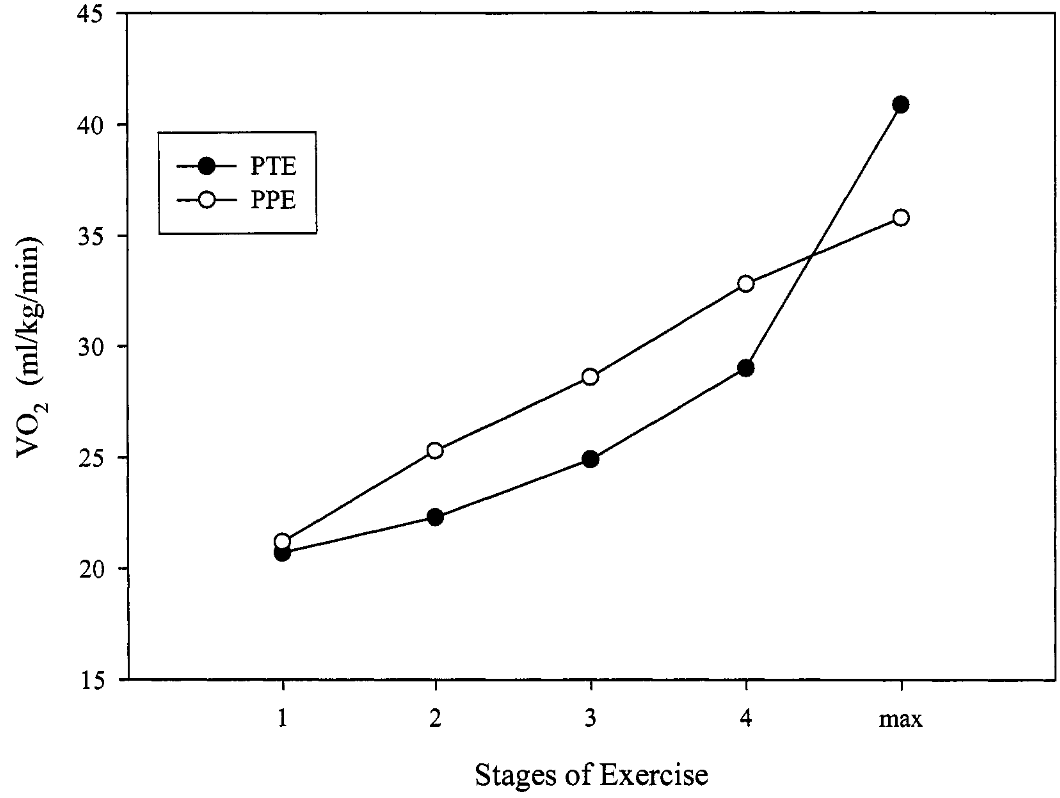

Figure B-1: Submaximal and Maximal VO_2 for Subject 1

The results of the economy portion of the pilot work for the female subjects are presented in Figure 2. As shown, the VO_2 in the PPE condition was consistently higher than in the PTE condition. In the PPE condition the slope is 0.88 while in the PTE condition the slope is 0.75. This suggests that as exercise intensity increases, the difference in VO_2 will increase between the two conditions.

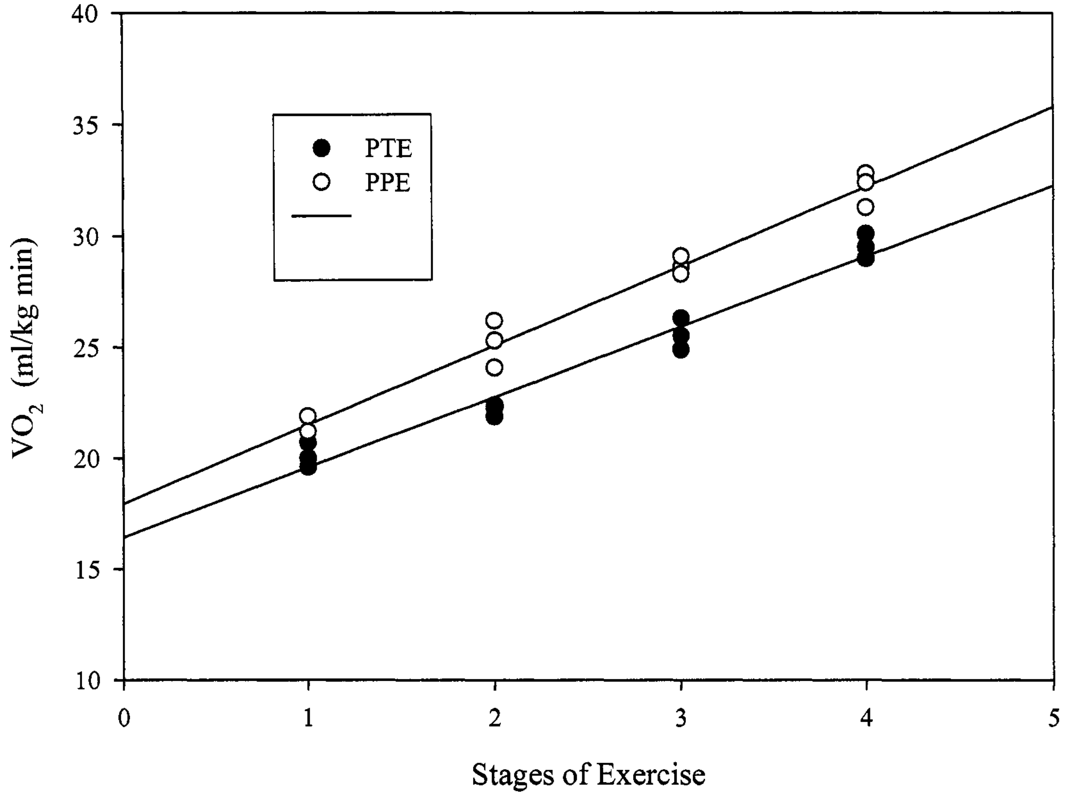

Figure B-2: Mean submaximal VO_2 for female subjects in PPE and PTE (n=3)

As expected, VO_{2max} in the PPE condition was lower than in the PTE condition. The difference was about nine percent for the pilot subjects, which is shown is Figure 3.

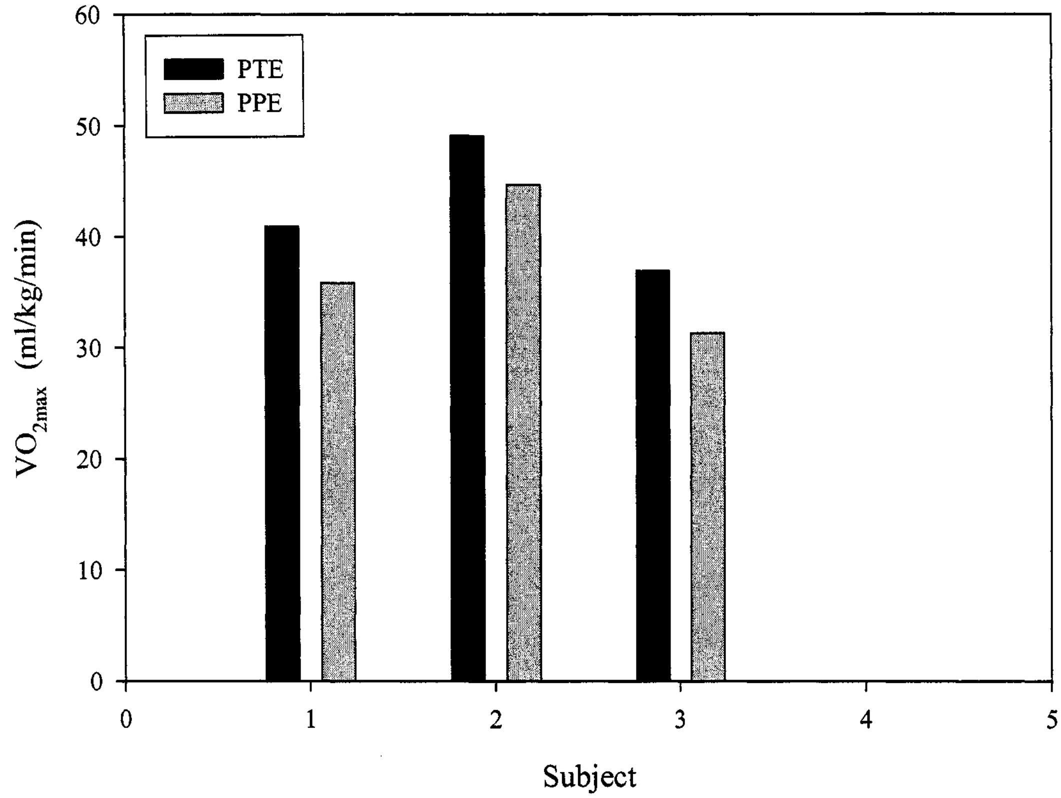

Figure B-3: VO_{2max} in PPE and PTE for the female subjects (n=3)

Interesting variables to investigate will be tidal volume, ventilation and breathing frequency. These are shown in Figures 4 to 6. In the PTE condition, both ventilation and tidal volume are lower during the submaximal loads and higher at VO_{2max} as compared to the values obtained in the PPE condition. Breathing frequency in PPE was higher in all stages of exercise with the first stage only showing a small difference. It is unclear if the differences in these variables will obtain significance with sufficient data to run a rigorous statistical analysis. The relative differences in ventilation, tidal volume, breathing frequency, VO_2 and power output are shown in Table 7. While it is beyond the scope of this study to elucidate whether the Kevlar® vest is specifically responsible for the changes in ventilation at VO_{2max}, it could suggest areas for future research.

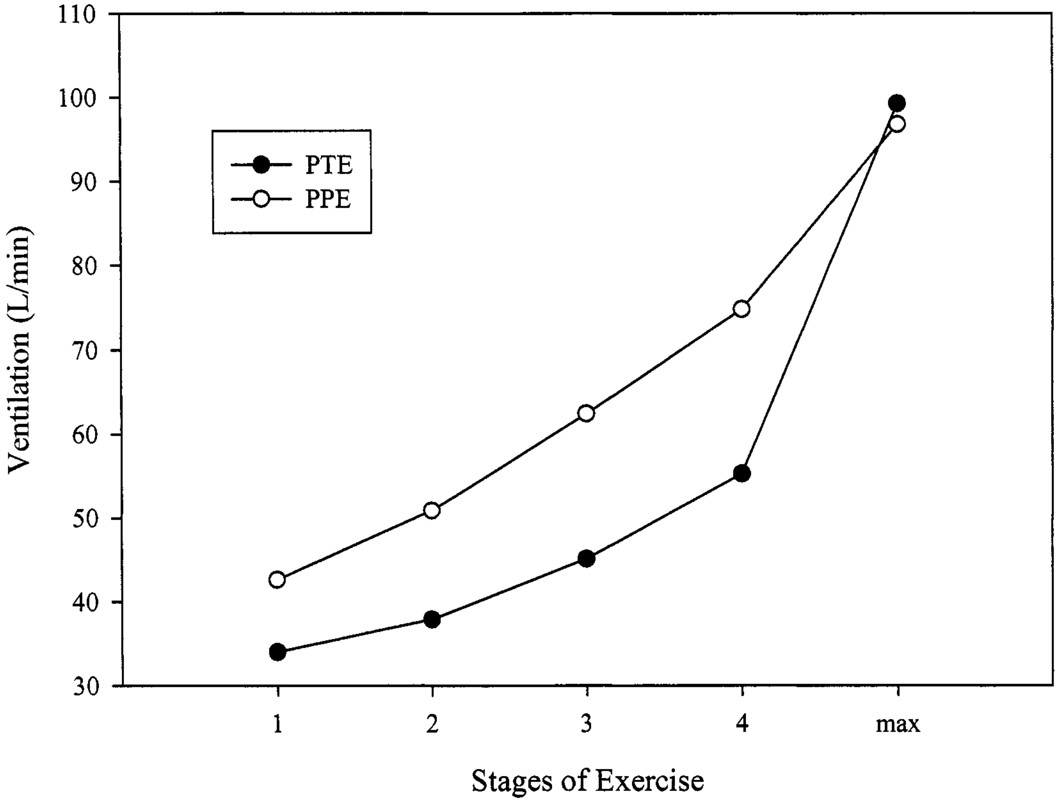

Figure B-4: Mean Ventilation in PPE and PTE for female subjects (n=3)

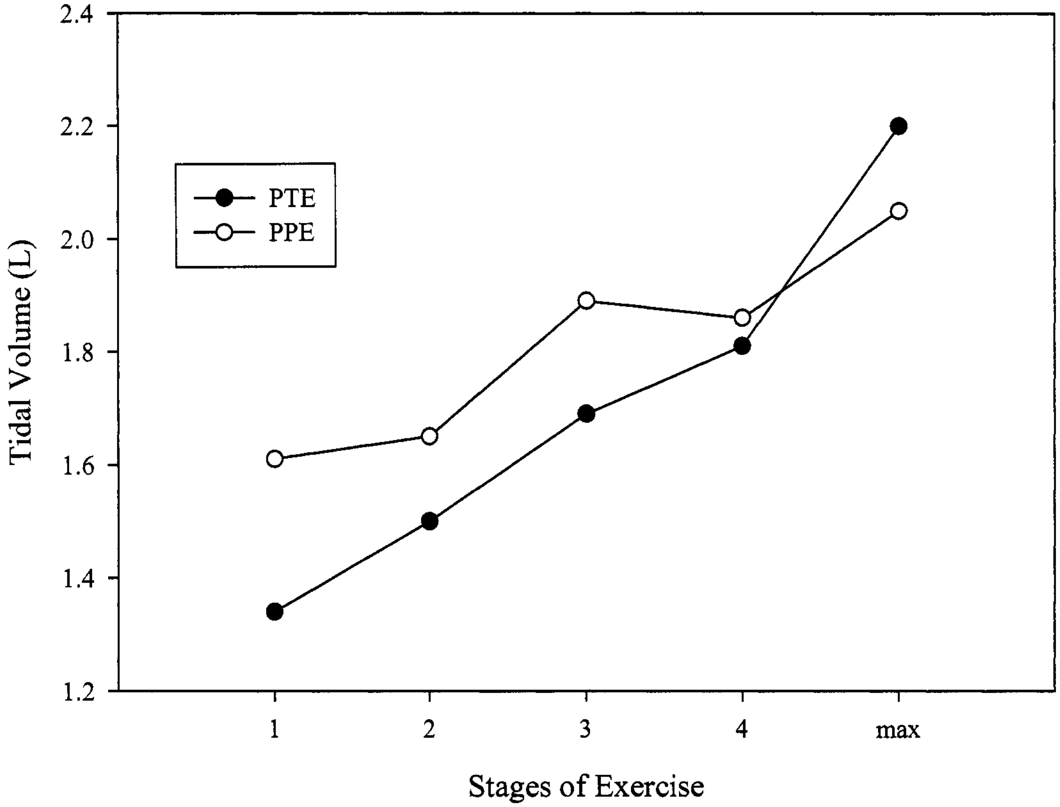

Figure B-5: Mean tidal volume in PPE and PTE for female subjects (n=3)

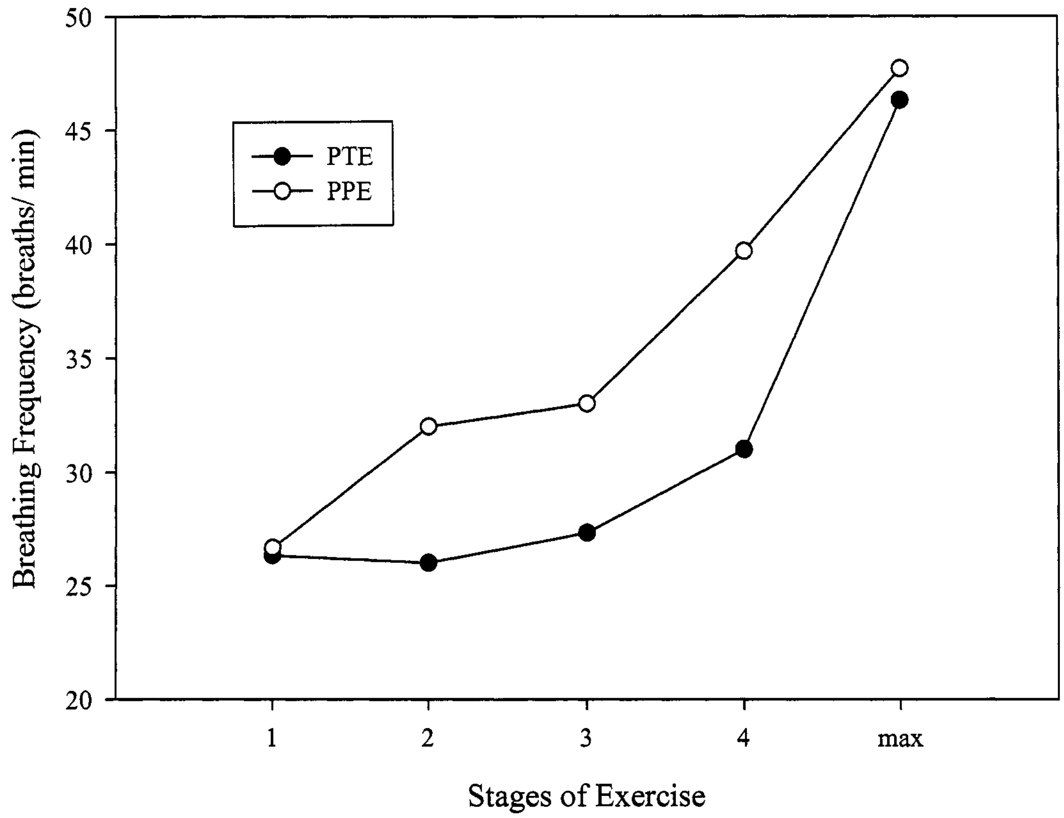

Figure B-6: Mean breathing frequency in PPE and PTE for female subjects (n=3)

Power output in the PTE condition was lower during the submaximal workloads and higher at the maximal loads as compared to the PPE condition. This was expected because of the extra weight carried in the PPE condition. The results of the study will determine if these differences are significant. Power output is shown in Figure 7.

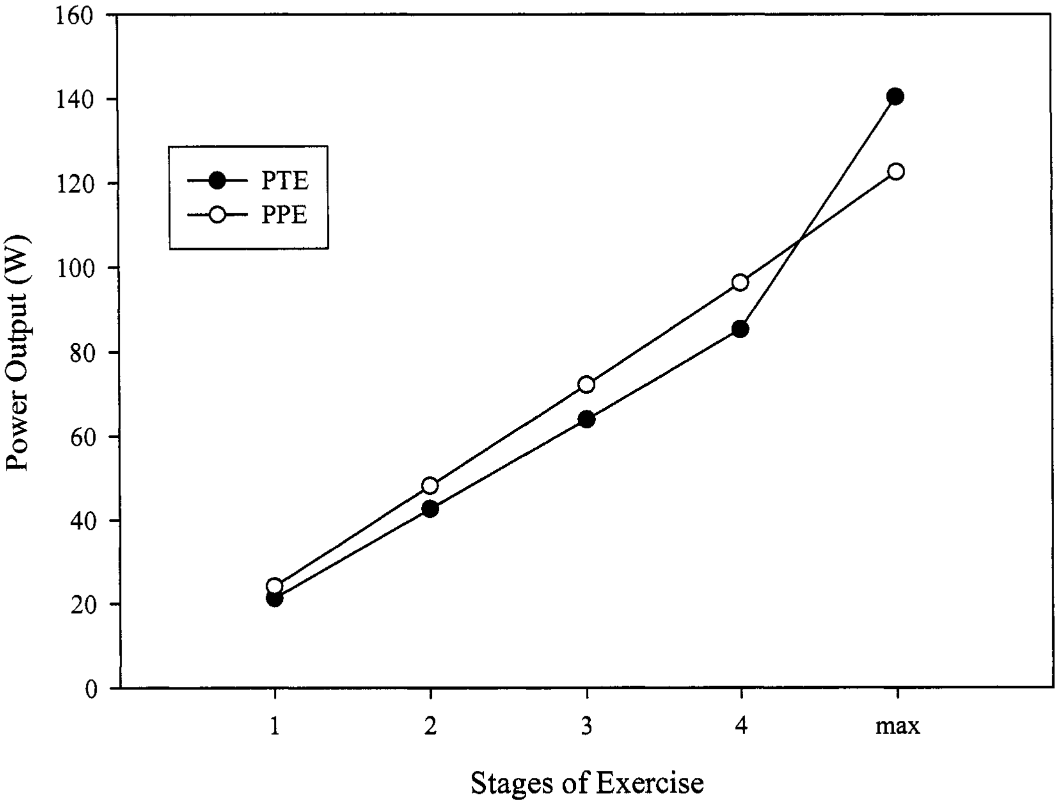

Figure B-7: Comparison of power output in PTE and PPE for the female subjects (n=3)

An interesting finding from the pilot work is the relative weight of the equipment for the subjects. The equipment weight ranged from 7.2 to 9 kg. However, when expressed relative to body mass, the equipment for the one male subject was 9% of his body weight and for the females, the equipment was between 11 and 14% of their body weight. The male was heavier than any of the females tested. This supports the idea that restricting the study to females may elicit a greater difference between the two states.

Table B-2

Variable comparisons expressed as PPE/PTE for female subjects (n=3)

Stages	VO_2	Ventilation	Breathing Frequency	Tidal Volume	Power Output
1	1.07	1.25	1.01	1.20	1.13
2	1.13	1.34	1.23	1.10	1.13
3	1.12	1.38	1.21	1.12	1.13
4	1.09	1.35	1.28	1.03	1.13
Max	0.88	0.97	1.03	0.93	0.87

The pilot work identified one problem with the protocol. One of the female police officers was in rather poor cardiovascular condition and reached her VO_{2max} at the end of the final economy stage (107.3 $m \cdot min^{-1}$, 8% grade). All the economy stages are designed for submaximal exercise. Because of this, an extra minute was added to the warm-up in order to obtain an additional submaximal load. The speed for subsequent submaximal loads was reduced to 94 $m \cdot min^{-1}$. This was done because it is anticipated that future subjects will be in similar condition yet the researcher will still be able to obtain a broad data set to work with. The final submaximal load will be optional based upon whether subjects reach anaerobic threshold during that stage. If they have, the final submaximal workload will be reduced to one minute and the test protocol will continue to volitional fatigue. The final protocol is presented in Appendix B.

Appendix C

Appendix D

Instructions for subjects:

1. Diet: Eat as you normally do. Do not eat anything unusual or increase/ decrease your consumption of food. Ensure that you are well hydrated. Please abstain from alcohol 24 hrs prior to each testing day. If you smoke, smoke as you normally would.

2. Police Equipment needed: Uniform, vest with trauma plate, full Danner boot, leather belt with the following: Glock holster, two sets of handcuffs, OC, flashlight, large baton, radio clip, extra magazine with rounds. You do not need your Glock as we have a red gun to use for the tests. If you need to bring it, we have a locked storage area that it can be secured. If you do not have any of the above equipment, just let me know as I have loaner equipment. If you need to remove anything, I will have an allen key so we can do it there.

3. The PT gear needed: shorts, t-shirt and running shoes.

4. Please bring any music (CD) that you choose to exercise to.

5. If you have exercise-induced asthma, please bring your medication.

6. On the day of the DEXA scan, eat breakfast as you normally would. Please abstain from alcohol or caffeine prior to the scan.

7. About 3-4 hours before the test, have a light snack such as yogurt and fruit, bagel, power bar, whatever gives you the energy for a good workout.

Name of Participant	**Signature of Participant**
Name of Witness	**Signature of Witness**
Name of Investigator	**Signature of Investigator**

Pregnancy Test Results (If applicable):

Signed documents must be kept for a minimum of five years

The treadmill GXT will begin with a warm-up walking at 3.5 mph at 1% grade. Every four minutes the grade will be increased by 2% while you continue to walk at 3.5 mph. After 16 minutes of walking, you will have a two-minute cool down followed by a five-minute rest. The second part of the test will start after the rest period with a brief warm-up. During the second part of the test, the treadmill speed will increase by 0.5 mph every minute at a consistent 8% grade until you need to stop. Each test will be conducted on a separate day and as much as possible, at the same time of day.

During the treadmill tests, your heart rate (HR) will be monitored continuously with a Polar monitor. Your HR is picked up by an elastic strap worn around the chest and is transmitted to a display unit.

During the treadmill tests you will breathe through a special valve system that allows us to measure the volume and the composition (amounts of oxygen and carbon dioxide) of the air with each breath. This information will be used to calculate the rate of oxygen consumption and your breathing responses during the tests.

At the end of each minute of the treadmill test we will ask you to give us a rating of physical exertion (RPE) using a special chart. We will explain how to use this chart before the test.

Table 1
Schedule for research

Test Day	Activity
1	Informed consent, screening
2	Practice GXT in PPE or PTE (random), Spirometry, MVV
3	Experimental GXT in PPE or PTE (random order), Spirometry, MVV
4	Experimental GXT in PPE or PTE (random order), Spirometry, MVV
5	DEXA scan

GXT – graded exercise test on a treadmill
Spirometry – evaluation of lung function (e.g., lung volumes, flow rates)
MVV – maximal voluntary ventilation
DEXA – Dual Energy X-Ray Absorptiometry

Each testing day just before the treadmill tests, you will be asked to perform two lung function tests: spirometry and maximal voluntary ventilation (MVV). This will require you breathing into a mouthpiece attached to a computer.

Before the DEXA scan, you must consent to a pregnancy test. This test is done at the Human Nutrition Research Centre immediately before the scan. Pregnant women will not be permitted to undergo a DEXA scan.

You will be asked to lie down on the DEXA table. Once you are properly positioned the technologist will start the test. The scanner arm will pass slowly from your head to your feet over a period of 5 minutes. During femur and spinal scans to measure bone density the scan arm will pass from your head to the small of the back, the technologist will then reposition you and direct the scan arm to pass over your hip area, each of these scans lasts approximately 30 seconds. It is important that you remain motionless during the scans. The total time commitment for the DEXA scan is about 30 minutes.

The amount radiation used in the body composition test (DEXA scan) is similar to the amount of radiation a person is exposed to in the environment on a daily basis. The radiation exposure during a bone density scan is slightly higher than during a body composition scan, and is similar to the radiation exposure during one commercial flight across Canada.

What is the time commitment?

It is estimated that the total time required to participate in this study should be about 6 hours over a period of two to three weeks. All tests will be scheduled at mutually convenient times.

What if I volunteer and then decide I don't want to continue?

You can withdraw from the research project at any time without consequence. You do not have to give a reason, simply tell one of the researchers that you do not want to continue. If you withdraw from the study, your information will be removed at your request.

Are there any risks involved?

The exercise challenges present very, low risk to healthy, physically active adults. However, there is always some health risk associated with maximal exercise. During and after the tests it is possible to experience symptoms such as abnormal blood pressure, fainting, lightheadedness, nausea, muscle cramps or strain and in very, rare cases, heart rhythm disturbances or heart attack. While serious risk to healthy individuals is extremely low, you should be aware of these possibilities and assume the risks associated with very hard exercise if you are to participate in this study.

We will use the health screening questionnaire and medical examinations as required to ensure that people who participate in the study are at minimal risk. The laboratory staff that will be conducting the research are trained to deal with

Appendix E

Data Sheets

Subject: ______________________
Date: ______________
Weight: ____________
Height: ____________
Age: ______________
PT Gear/ Equipment

Signal Display:
O2 ______ ______
CO2 _____ _______

Max HR: ________________

Time	% Grade	Speed	HR	RPE/ Frequ
1	***1***	***3.5***		
2	***1***	***3.5***		
3	***1***	***3.5***		
4	***1***	***3.5***		
5	3	3.5		
6	3	3.5		
7	3	3.5		
8	3	3.5		
9	***5***	***3.5***		
10	***5***	***3.5***		
11	***5***	***3.5***		
12	***5***	***3.5***		
13	7	3.5		
14	7	3.5		
15	7	3.5		
16	7	3.5		
17	***0***	***2.5***		
18	***0***	***2.5***		

Music ___________

Subject: ________________________
Date: _______________
Weight: _____________
Height: _____________
Age: _______________
PT Gear/ Equipment

Signal Display:
O2 ______
CO2 _________

Max HR: ________________

Time	% Grade	Speed	HR	RPE
1	0	3.5		
2	4	3.5		
3	6	3.5		
4	8	3.5		
5	8	4.0		
6	8	4.5		
7	8	5.0		
8	8	5.5		
9	8	6.0		
10	8	6.5		
11	8	7.0		
12	8	7.5		
13	8	8.0		
14	8	8.5		
15	8	9.0		
16	8	9.5		
17	9	10.0		

Cool Down

1	0	2.5		
2	0	2.5		
3	0	2.5		

Appendix F

Raw Data and Figures

Table F-1

DEXA leg measurements (n=30)

	Average	SD	Minimum	Maximum
Tibia (cm)	36.86	2.10	32.34	42.00
Femur (cm)	42.16	2.30	36.64	47.07
Total length (cm)	79.01	4.20	68.98	87.51

Table F-2

VO_{2peak} results for test and experimental trials in the PTE condition (n=16)

	Average VO_{2peak}	SD	Minimum	Maximum
Trial ($ml \cdot kg^{-1} \cdot min^{-1}$)	42.2	3.4	36.3	50.8
Trial ($L \cdot min^{-1}$)	2.79	.42	2.24	3.75
Experimental ($ml \cdot kg^{-1} \cdot min^{-1}$)	43.0	2.9	37.4	49.7
Experimental ($L \cdot min^{-1}$)	2.82	.40	2.26	3.84

Table F-3

VO_{2peak} results for test and experimental trials in the PPE condition (n=14)

	Average VO_{2peak}	SD	Minimum	Maximum
Trial ($ml \cdot kg^{-1} \cdot min^{-1}$)	39.2	3.4	35.2	46.2
Trial ($L \cdot min^{-1}$)	2.88	.38	2.17	3.47
Experimental ($ml \cdot kg^{-1} \cdot min^{-1}$)	39.6	3.2	34.6	46.4
Experimental ($L \cdot min^{-1}$)	2.90	.37	2.07	3.45

Table F-4

Stride frequency results for the submaximal workloads for female police officers (n=30) in PPE and PTE conditions

	PTE Mean (SD)	**PPE Mean (SD)**	***PTE Range***	**PPE Range**
Stage 1	62 (4)	61 (3)	56-72	56-68
Stage 2	62 (3)	62 (4)	56-70	56-70
Stage 3	62 (3)	62 (3)	56-72	56-70
Stage 4	62 (3)	62 (4)	56-72	56-70

Table F-5

Power output results for submaximal (Stage 1-4) and maximal workload (Stage 5) for female police officers (n=30) in both PTE and PPE conditions

	PTE Mean (W) (SD)	**PPE Mean (W) (SD)**	**PTE Range (W)**	**PPE Range (W)**
Stage 1	10.04 (1.04)	11.32 (1.05)	7.93-13.04	8.99-14.26
Stage 2	30.13 (3.10)	33.96 (3.15)	23.79-39.11	26.96-42.79
Stage 3	50.22 (5.18)	56.60 (5.26)	39.65-65.19	44.94-71.32
Stage 4	70.31 (7.24)	79.24 (7.36)	55.51-91.26	62.92-99.85
Stage 5	159.09 (26.92)	157.16 (25.46)	109.48-254.87	113.76-247.14

Table F-6

RER results for both submaximal (Stages 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n = 29) in PTE and PPE conditions

	***PTE Mean* (SD)**	**PPE Mean (SD)**	**PTE Range**	**PPE Range**
Stage 1	0.84 (0.04)	0.87 (0.05)	0.71-0.92	0.75-0.97
Stage 2	0.88 (0.04)	0.91 (0.04)	0.71-0.95	0.78-0.99
Stage 3	0.89 (0.04)	0.92 (0.05)	0.76-0.96	0.77-1.02
Stage 4	0.90 (0.05)	0.94 (0.05)	0.75-0.99	0.81-1.02
Stage 5	1.16 (0.05)	1.16 (0.06)	1.05-1.24	1.01-1.29

Table F-7

Ventilation results submaximal (Stage 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n = 29) in PTE and PPE conditions

	PTE Mean (L·min^{-1}) (SD)	**PPE Mean (L·min^{-1}) (SD)**	**PTE Range (L·min^{-1})**	**PPE Range (L·min^{-1})**
Stage 1	28.59 (3.41)	33.70 (4.28)	21.17-36.02	24.23-46.09
Stage 2	33.37 (4.10)	40.24 (4.92)	24.11-43.91	30.63-54.80
Stage 3	38.10 (4.93)	46.92 (6.86)	27.92-51.08	34.17-67.62
Stage 4	43.94 (7.12)	55.46 (7.18)	29.37-64.20	41.02-74.91
Stage 5	102.00 (13.01)	102.30 (12.83)	85.04-129.48	79.04-130.72

Table F-8

VCO_2 results for submaximal (Stages 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n = 29) for PTE and PPE conditions

	PTE Mean ($L \cdot min^{-1}$) (SD)	PPE Mean ($L \cdot min^{-1}$) (SD)	PTE Range ($L \cdot min^{-1}$)	PPE Range ($L \cdot min^{-1}$)
Stage 1	0.91 (0.12)	1.10 (0.14)	0.67-1.13	0.78-1.45
Stage 2	1.09 (0.14)	1.34 (0.14)	0.79-1.37	0.99-1.69
Stage 3	1.26 (0.15)	1.56 (0.18)	0.92-1.58	1.14-2.01
Stage 4	1.46 (0.20)	1.82 (0.18)	1.03-1.91	1.35-2.12
Stage 5	3.24 (0.46)	3.24 (0.49)	2.41-4.49	2.47-4.62

Table F-9

Heart rate results for submaximal (Stages 1-4) and maximal (Stage 5) for female police officers (n=30, except stage 4 where n = 29) for PTE and PPE conditions.

	PTE Mean (BPM) (SD)	PPE Mean (BPM) (SD)	PTE Range (BPM)	PPE Range (BPM)
Stage 1	109 (13)	120 (14)	83-133	94-149
Stage 2	118 (14)	134 (15)	91-145	105-164
Stage 3	128 (14)	148 (17)	101-154	116-177
Stage 4	139 (16)	159 (16)	108-165	131-183
Stage 5	186 (7)	188 (8)	169-199	175-207

Table F-10

Breathing frequency (bpm) results for submaximal (Stages 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n = 29) in PTE and PPE conditions

	PTE Mean (bpm) (SD)	PPE Mean (bpm) (SD)	PTE Range (bpm)	PPE Range (bpm)
Stage 1	23 (4)	25 (4)	12-31	19-34
Stage 2	25 (4)	27 (4)	16-31	19-37
Stage 3	26 (4)	29 (5)	16-33	21-42
Stage 4	28 (4)	32 (5)	20-37	24-46
Stage 5	47 (5)	49 (4)	38-63	40-58

Table F-11

Relative VO_2 results for submaximal (Stages 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n = 29) in PTE and PPE conditions

	PTE Mean ($ml \cdot kg^{-1} \cdot min^{-1}$) (SD)	PPE Mean ($ml \cdot kg^{-1} \cdot min^{-1}$) (SD)	PTE Range ($ml \cdot kg^{-1} \cdot min^{-1}$)	PPE Range ($ml \cdot kg^{-1} \cdot min^{-1}$)
Stage 1	16.5 (1.7)	17.3 (1.6)	12.0-19.2	13.6-19.8
Stage 2	18.8 (1.8)	20.0 (1.6)	14.9-21.7	16.1-22.6
Stage 3	21.6 (1.9)	22.9 (1.9)	17.0-24.5	18.5-25.2
Stage 4	24.8 (2.2)	26.2 (2.0)	19.1-28.2	21.7-28.9
VO_{2peak}	44.0 (3.6)	38.8 (3.6)	37.4-53.4	32.6-48.5

Table F-12

Absolute VO_2 results for submaximal (Stages 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n = 29) in PTE and PPE conditions

	PTE Mean ($L \cdot min^{-1}$) (SD)	PPE Mean ($L \cdot min^{-1}$) (SD)	PTE Range ($L \cdot min^{-1}$)	PPE Range ($L \cdot min^{-1}$)
Stage 1	1.08 (0.13)	1.27 (0.14)	0.78-1.28	0.97-1.55
Stage 2	1.23 (0.15)	1.47 (0.16)	0.91-1.52	1.14-1.81
Stage 3	1.41 (0.16)	1.69 (0.18)	1.02-1.66	1.33-2.02
Stage 4	1.62 (0.19)	1.93 (0.18)	1.19-2.00	1.54-2.23
Stage 5	2.88 (0.41)	2.87 (0.42)	2.10-3.84	2.07-3.91

Table F-13

Tidal volume results for submaximal (Stages 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n = 29) in PTE and PPE conditions

	PTE Mean (L) (SD)	PPE Mean (L) (SD)	PTE Range (L)	PPE Range (L)
Stage 1	1.25 (0.28)	1.36 (0.21)	0.75-2.10	0.87-1.86
Stage 2	1.36 (0.26)	1.49 (0.21)	0.85-2.12	1.05-1.93
Stage 3	1.47 (0.28)	1.61 (0.24)	0.96-2.42	1.11-2.33
Stage 4	1.61 (0.27)	1.73 (0.23)	1.07-2.35	1.22-2.22
Stage 5	2.19 (0.29)	2.11 (0.26)	1.62-2.82	1.63-2.68

Table F-14

RPE results for submaximal (Stages 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n = 29) in PTE and PPE conditions

	PTE Mean (SD)	PPE Mean (SD)	PTE Range	PPE Range
Stage 1	6 (1)	7 (2)	6-8	6-13
Stage 2	7 (1)	9 (2)	6-10	6-16
Stage 3	8 (2)	10 (3)	6-13	6-18
Stage 4	10 (3)	12 (3)	6-15	6-19
Stage 5	18 (1)	18 (1)	15-20	15-20

Table F-15

Run Start Times (n=28) and Total Exercise Times (n=30) for PTE and PPE

	Mean	SD	Minimum	Maximum
Run Start PTE (min)	4.78	.51	4.07	6.05
Run Start PPE (min)	4.71	.54	4.05	6.06
Run Time PTE (min)	9.90	1.33	7.53	13.00
Run Time PPE (min)	8.06	1.17	6.07	11.17

Table F-16

Lung Function Tests For Female Police Officers (n=30) in PTE and PPE Condition

	PTE Mean (SD)	**PPE Mean (SD)**	**PTE Range**	**PPE Range**
MVV ($l \cdot min^{-1}$)	127.1	125.2	86.8-167.5	86.1-167.4
	(20.1)	(16.7)		
% Predicted MVV	111.2	109.5	77.5-158.7	76.6-136.2
	(18.8)	(16.7)		
FVC (l)	4.3	4.2	3.3-6.0	3.3-5.6
	(0.6)	(0.6)		
% Predicted FVC (n=28)	109.8	105.8	89.8-146.9	87.4-144.8
	(14.5)	(13.2)		
FEV_1 (l)	3.5	3.4	2.84.7	2.7-4.4
	(0.5)	(0.5)		
% Predicted FEV_1 (n=28)	105.6	100.7	78.8-154.6	76.6-148.7
	(15.6)	(14.9)		

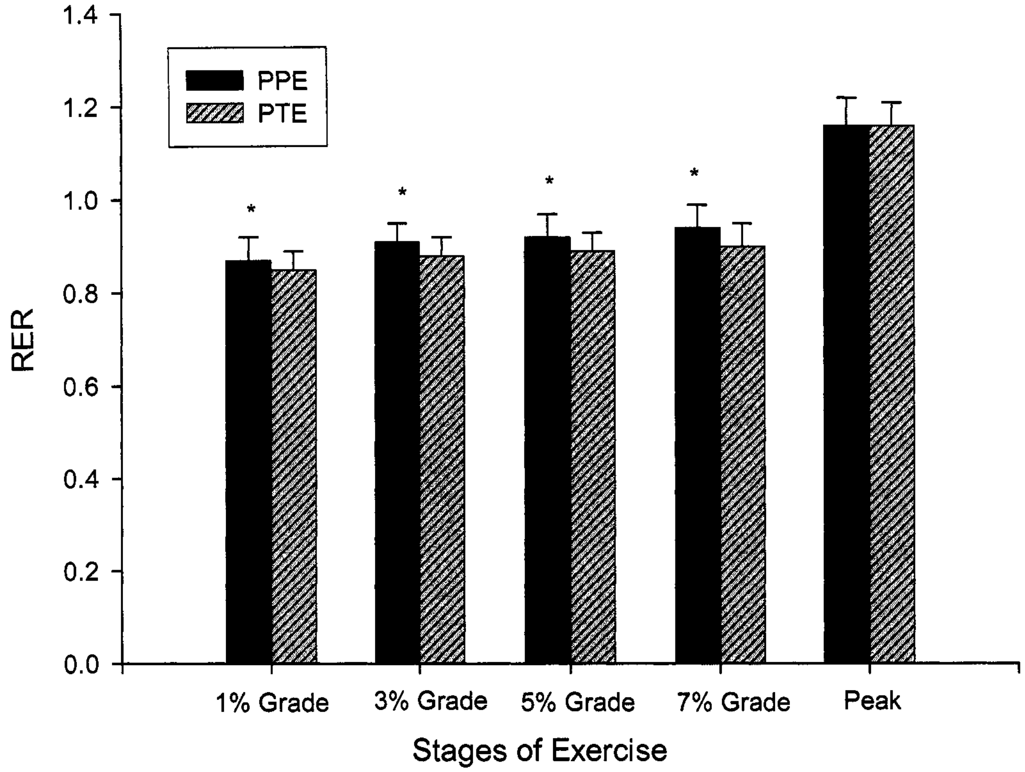

Figure F-1: RER for submaximal (Stages 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n=29) in PTE and PPE conditions, * p≤ 0.05 between conditions.

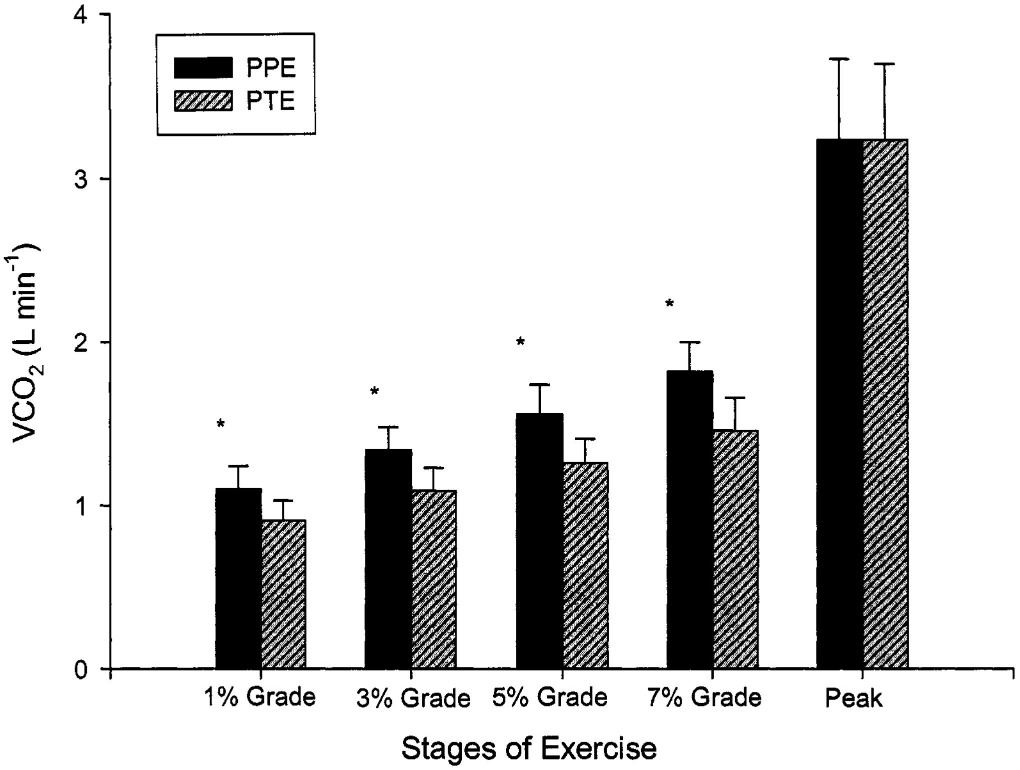

Figure F-2: VCO_2 for submaximal (Stage 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n=29) in PTE and PPE conditions, * $p \leq 0.05$ between conditions.

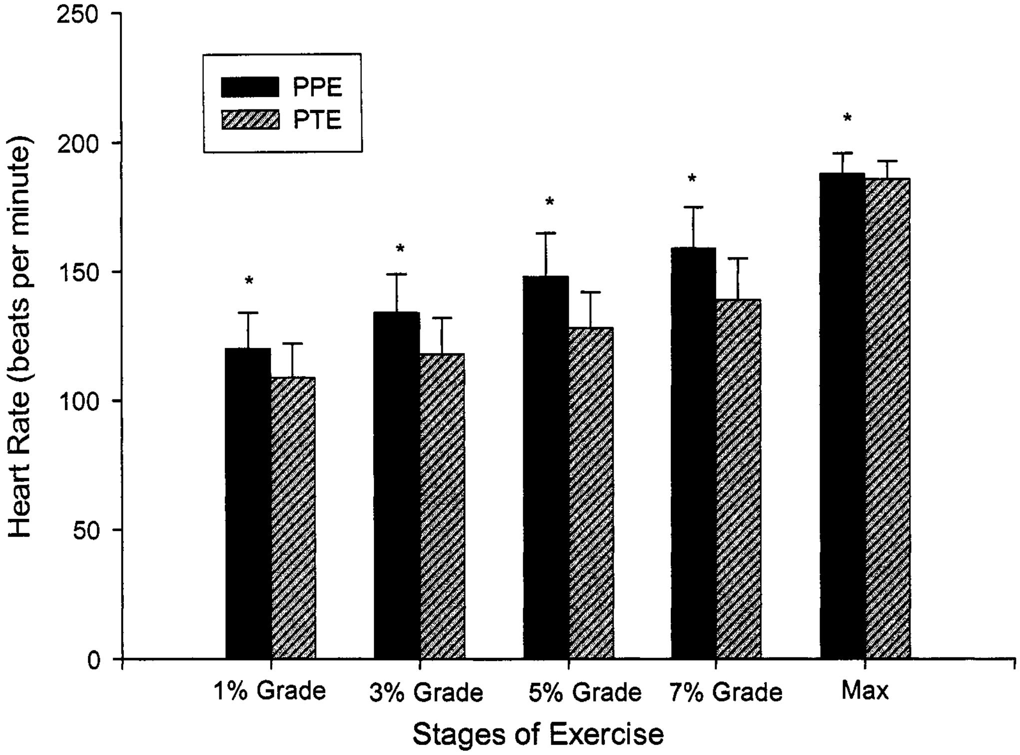

Figure F-3: Heart rate for submaximal (Stages 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n=29) in PTE and PPE conditions, * $p \leq 0.05$ between conditions.

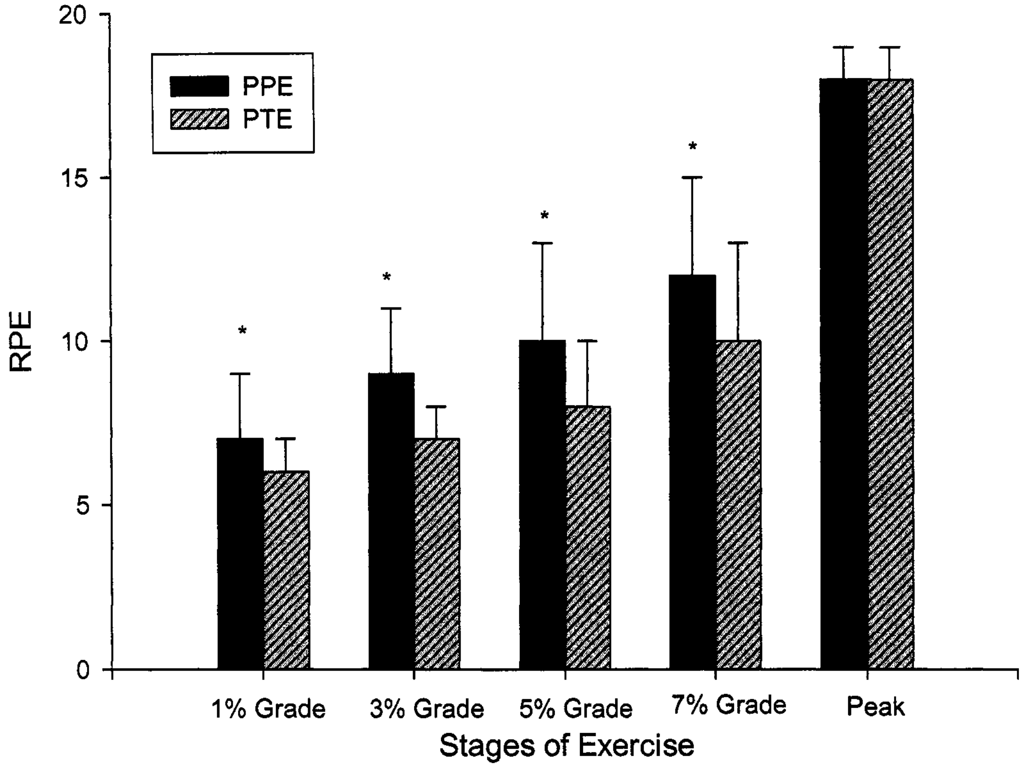

Figure F-4: Rate of perceived exertion (RPE) for submaximal (Stages 1-4) and maximal (Stage 5) workloads for female police officers (n=30, except stage 4 where n=29) in PTE and PPE conditions, * $p \leq 0.05$ between conditions.