The Impact of Police Duty Ensemble on the Cardiopulmonary Response to Exercise and Simulated Work Performance

by

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Abstract

This study, conducted in two-parts, examined the impact of general duty police ensemble on the cardiopulmonary response to graded exercise and on simulated work performance in 25 healthy male and female subjects. Part I consisted of randomly ordered treadmill tests in two experimental conditions: physical training (PT, undergarments, shorts, t-shirt, and running shoes) and police duty ensemble (PDE, undergarments, body armour, patrol uniform, boots, duty belt with required small equipment, radio and weapons). The PDE added 10.3 ± 0.4 kg, or 14 ± 2% body mass. Subjects walked at 93.9 $m \cdot min^{-1}$, starting at 0% grade with 2% increases in grade every two minutes. The stage at 4% grade was extended to six minutes to allow measurement of steady-state responses. Part II evaluated performance time on a job-related, pursuit-restraint simulation circuit used to test physical aptitude in police applicants, in three experimental conditions; PT (as above), weighted belt (WB, PT plus a 7.5 kg weighted belt), and PDE (as above). In Part I, physiological responses such as $\dot{V}O_2$, $\dot{V}_E$, and heart rate, were elevated ($p<0.05$) with PDE during submaximal exercise but peak values were unchanged. Test duration and peak power output were significantly reduced with PDE. In Part II, circuit completion time was increased in PDE compared to PT and WB ($p<0.05$). Heart rate and perceived exertion were similar in all conditions; however, perceived dyspnea was higher in PDE. Results show that general duty police ensemble increased physiological strain, resulting in reduced peak exercise performance as well as reduced performance during simulated police work.

Preface

This thesis is an original work by Cameron Michael Ehnes. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, project name "The Impact of Police Equipment on the Cardiopulmonary Responses to Treadmill Exercise and Simulated Police Work", Pro00075940, September 2017. The project also had a subsequent amendment that received research ethics approval from the University of Alberta Research Ethics Board, project name "The Impact of Police Equipment on the Cardiopulmonary Responses to Treadmill Exercise and Simulated Police Work", Pro00075940_AME1, February 2018. The equipment for this project was supplied by the Edmonton Police Service under proper authority and with agreements in place. There are no conflicts of interest.

Dedication

The work contained in this thesis has a simple mission: to characterize and understand the impact of police duty ensemble on human physiology and human performance. While this thesis attempts to get us closer to understanding the job of law enforcement officers, those of us who have not walked in their shoes will never totally understand what they go through in the performance of their duties.

To those that humbly serve and protect our communities and to the loved ones that quietly stand behind them; your service does not go unnoticed or unappreciated.

To those who have given their lives in the line of duty; thank you, you are not forgotten.

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Glossary of Terms

A-PREP: Alberta Physical Readiness Evaluation for Police.

PT: Physical Training.

WB: Weight Belt.

PDE: Police Duty Ensemble.

FVC: Forced Vital Capacity (L).

FEV_1: Forced Expired Volume in 1 Second (L).

PEFR: Peak Expiratory Flow Rate ($L \cdot s^{-1}$).

IC: Inspiratory Capacity (L).

$\dot{V}_A$: Alveolar Ventilation.

$\dot{V}_D$: Deadspace Ventilation.

PCO_2: Partial Pressure of Carbon Dioxide.

$PaCO_2$: Partial Pressure of Arterial Carbon Dioxide.

$P_{ET}CO_2$: Partial Pressure of End-Tidal Carbon Dioxide (mmHg).

$\Delta M_{Pressure}$: Mouth Pressure Swing (peak minus minimum) (cmH_2O).

Chapter 1 – Introduction

1.1 Background

Standard issue equipment for general service police officers consists of a uniform, boots, duty belt with required small equipment (*e.g.* ammunition, handcuffs), weapons, soft body armour, and communications equipment (Dempsey *et al.* 2013). Historically, the load carried by the general service police officer has increased (Taylor *et al.* 2009). This is due to many factors but was primarily driven by the development of soft body armour appropriate for patrol wear throughout the 1970s (Taylor *et al.* 2009). The mass of the equipment worn by officers varies somewhat between organizations, but locally, the minimum required equipment carried by members of the Edmonton Police Service weighed approximately 8.5 ± 0.6 kg in 2005 (Pagé 2005), and has increased to 10.3 ± 0.4 kg currently.

Load carriage is known to increase metabolic demand (Goldman and Iampietro 1962). The magnitude of increase in metabolic demand depends primarily on load mass and location. Metabolic cost increases disproportionately with increased load mass, and some body locations elicit a higher metabolic cost than others at a constant mass (Taylor *et al.* 2012; Phillips *et al.* 2016d). Despite increased metabolic demand due to thoracic load carriage, the reduction of physiological maxima such as $\dot{V}O_{2peak}$, is small with load carriage up to 26 kg (Louhevaara *et al.* 1995; Taylor *et al.* 2012; Phillips *et al.* 2016a). However, load carriage does result in a substantial reduction in exercise performance (Louhevaara *et al.* 1995; Dempsey *et al.* 2013; Phillips *et al.* 2016a,b,c). As exercise is an important element of police work, understanding the impact of the duty ensemble on exercise responses and performance is of importance.

The impact of various forms of occupational load carriage on performance has been documented in the literature. The occupations examined have included structural firefighting, wildland firefighting, military, and law enforcement, and in all cases, the performance of subjects was reduced while completing mobility tasks, job-related tasks, or tests of physical readiness for work (Polcyn *et al.* 2002; Dempsey *et al.* 2013; Taylor *et al.* 2015; Lewinski *et al.* 2015). This has implications for work standards and work practices where mobility is key for the successful and safe completion of a task or resolving a critical incident. In the context of police officers, mobility is the ability to be physically responsive on foot while moving through multiple planes, navigating environmental obstacles, changing direction rapidly, and applying large amounts of physical force with precision (*e.g.* apprehending a suspect while using appropriate force). General service police duty ensemble has been previously reported to increase metabolic demand and reduce performance during treadmill (Pagé 2005) and stepping exercise (DiVencenzo *et al.* 2014). The interaction between load carriage and performance on complex tasks involving a combination of agility, speed, and strength is the foundation for many tests of physical aptitude for police work (Jamnik *et al.* 2013). Two examples of these tests, which simulate essential elements of police work, are the Physical Abilities Readiness Evaluation (PARE), used by the Royal Canadian Mounted Police (Bonneau and Brown, 1995), and the Alberta Physical Readiness Evaluation for Police (A-PREP), used by police services in Alberta (Gledhill and Jamnik, 2007; Gumieniak *et al.* 2013). Both of these tests are conducted in a continuous circuit style while participants navigate directional change, vertical displacement challenges, weight-resisted pushing and pulling, and dragging or carrying a simulated victim or object (Bonneau and Brown, 1995; Gledhill and Jamnik, 2007). While there is some research to document the impact of police duty ensemble on treadmill, stepping, and discrete mobility task performance, there is only one study on the impact of police duty ensemble on performance during simulated work (Marins et al. 2018). The latter paper, from Brazil, examined physiological responses and performance on an obstacle course for highway patrol officers. Clothing and equipment configurations can be expected to differ between jurisdictions so it is difficult to predict whether those results can be generalized to other jurisdictions or types of police work.

Body armour is known to alter resting pulmonary function, and this varies with type, mass, and fit profile (Legg 1988; Armstrong and Gay 2016). Standard issue Edmonton Police Service body armour is a Type-II armour, according to the classification standards set out by the United States National Institute of Justice (Taylor *et al.* 2009). This style of body armour consists of front and back panels, made of ballistic resistant fabric such as Kevlar. The panels have centrally located slots for ballistic or trauma plates that provide extra protection over critical tissue areas, and the panels are secured to the front and back of the thorax with Velcro straps over the shoulders and around the stomach. Importantly, this type of body armour is lightweight, close fitting, and designed to be worn under a patrol uniform for the duration of an officer's time on duty. During submaximal exercise, the ensemble has been shown to increase minute ventilation, breathing frequency, and tidal volume, likely due to increased metabolic demand associated to the additional carried mass (Pagé 2005). At peak exercise while wearing body armour breathing frequency was increased, tidal volume was decreased, and minute ventilation was unchanged with respect to an unloaded control (Pagé 2005). The reason for a decrease in tidal volume is not currently known, but may be related to the fit characteristics of body armour and the limitations on normal chest wall excursion. Whether alterations in resting spirometry or chest wall excursion translate to constrained minute ventilation during heavy exercise is unknown.

1.2 Purpose and Hypothesis

The purpose of this study was two-fold: first, to examine the physiological response during submaximal graded and maximal graded treadmill exercise with police duty ensemble; and second, to examine the impact of police duty ensemble on job-related performance using a recognized work simulation as a model for police work.

It was hypothesized that during submaximal exercise minute ventilation, breathing frequency, and tidal volume would be increased with the police equipment when compared to an unloaded control. This increase would be proportional to an increase in metabolic demand associated to the load carriage component of the equipment. During peak exercise, it was hypothesized that the duty ensemble would lead to compensatory changes in breathing pattern (tidal volume and breathing frequency) in order to maintain alveolar ventilation.

It was hypothesized that during the work simulation, heart rate, rating of perceived exertion, and rating of perceived dyspnea, would be similar and near maximal for all conditions. Concomitant with the consistently high physiological strain, an increase in completion time would be observed with police duty ensemble.

1.3 Significance

There is evidence that metabolic demand is increased with police duty ensemble when compared to an unloaded control during exercise (Pagé 2005; DiVencenzo *et al.* 2014). During exercise, perceived exertion is also increased with respect to the unloaded control (Pagé 2005; DiVencenzo *et al.* 2014). The current study provides a more detailed analysis of the components of ventilation, specifically: breathing pattern and operating lung volume during a graded exercise protocol. The unpublished thesis of Pagé (2005) served as the primary body of work in aiding the development of the hypothesis for this project.

The A-PREP protocol is a recognized task simulation that includes numerous tasks relevant to policing. Participants require many physical abilities including strength, speed, agility, and mobility to successfully complete the simulation. Evaluation of performance on the simulation with police duty ensemble highlights the potential impact of the ensemble on real world work performance on similar tasks. This type of evaluation continues to be important as occupational equipment and work practices are always changing.

By incorporating both a lab-based exercise protocol and a recognized work simulation model, the effects of police duty ensemble were studied in different modes of exercise and over a range of intensities. Each condition provided different information (*e.g.* submaximal steady state, graded exercise, maximal, mobility, strength, change of direction). The combination of lab-based and work simulation data provided a more complete picture of the impact of police duty ensemble on human physiology and performance. Understanding the impact of police duty ensemble has implications for training and physical employment standards, injury reduction, occupational health and safety, and occupational effectiveness.

1.4 Delimitations (Scope)

1.4.1 Subjects

The sample in this study, which included both males and females, had similar characteristics to typical male and female police force applicants (Table 3-1) (S.J. Lemelin, personal communication, 2018). This investigation did not explore questions related to sex differences as primary outcomes. Any discussion of sex differences located in the general discussion of this thesis (Chapter 4) is purely speculative. Subjects were screened for health status prior to exercise participation and persons with known cardiopulmonary disease were excluded from the study. One male participant was identified to have possible exercise-induced bronchoconstriction (EIB). However, after careful review of his pre-exercise spirometry and exercise operating lung volume data, his results were included for analysis because the responses were considered normal. Potential participants that worked rotating schedules were excluded from the study in the interest of ease of scheduling and timely study completion.

1.4.2 Variables of Interest

The independent variables in this study were the loaded and unloaded conditions. The dependant variables in Part I, the lab component, were the responses in physiological parameters including operational lung volume, breathing pattern, mouth pressure swing, oxygen consumption, heart rate, rating of perceived exertion, rating of perceived dyspnea, and graded exercise test performance time. The dependent variables in Part II, the work simulation component, were heart rate response, rating of perceived exertion, rating of perceived dyspnea, and performance time.

Before and during treadmill exercise in the lab component, ventilatory parameters were measured, including: operational lung volume, breathing pattern, inspiratory capacity (IC), the pressure of end-tidal carbon dioxide ($P_{ET}CO_2$), and mouth pressure. In addition, spirometry was evaluated before and after exercise. Rating of perceived exertion and rating of perceived dyspnea were collected using modified Borg perceptual scales (Borg 1982).

Before, during, and after the A-PREP component, physiological strain indicators were measured, including: heart rate, rating of perceived exertion, and rating of perceived dyspnea. Performance time on the work simulation was also measured.

1.4.3 Exercise Protocols

The exercise protocols in this study allowed us to study the impact of police duty ensemble in a variety of exercise modes and experimental conditions. All pre-exercise fitting and familiarization protocols followed a model that had proven effective in previous studies (Phillips *et al.* 2016a,b,c,d; Phillips *et al.* 2018a).

A motorized treadmill was used during the lab component, set at a constant speed with adjustments made to the grade at standardized time intervals. The extended stage at 4% grade was selected to achieve a sustainable sub-maximal intensity for all subjects so that steady-state responses could be recorded. The intensity of the exercise in the work simulation was self-selected, but subjects had ample practice and were encouraged to work at an intensity that would give them their best possible performance time on the test.

1.4.4 Testing Environment and Preparation

All exercise testing occurred in an air-conditioned laboratory or gymnasium under temperate atmospheric conditions with very little day-to-day variation (typically 20^{o} C ± 1^{o} C, 706 ± 6 mmHg, and 7 ± 5% RH).

Exercise testing sessions were separated by no less than 24 hours in order to minimize the effects of fatigue. Prior to each day of participation, subjects were given guidelines regarding nutrition, sleep, and exercise outside of the study in order to maintain a similar pre-participation physiological state. All testing sessions were booked at similar times of the day in order to minimize any effects diurnal variation could have on performance.

1.5 Limitations

1.5.1 Equipment

Body armour and police duty belts must fit properly in order to be used effectively. Body armour was sized and fitted according to the guidelines provided by the National Institute of Justice (Sabol *et al.* 2014). The equipment provided by the Edmonton Police Service fit a range of body sizes for both sexes, however, in EPS, the amour is custom fit for each officer. It is possible that custom fitting may have brought the garment fit closer to ideal specifications, but this was simply not feasible for this study. With both body armour and duty belts, the equipment fit was consistent with the manufacturer's specifications and once fit was established, the measurements for all adjustment positions were confirmed before each exercise trial. The specific protocol used and a breakdown of equipment is detailed in Appendix A.

1.5.2 Environmental and Occupational Considerations

In actual police work, speed, grade, and groundcover are variable and unpredictable depending on the area of police operations and this may present additional challenges to the workers. Further, police work is completed in all environmental conditions, which cannot be replicated in a laboratory setting.

During the A-PREP component, the testing circuit is a work simulation designed to test the physical abilities required at a basic level in order to chase and apprehend a suspect. In real police work, the chase and apprehension of suspects is unique to each situation and no work simulation can capture all possible realities.

1.5.3 Subject Motivation

The exercise trials in this study were challenging. Thus, it was important to recruit subjects that were not only fit but also interested in the study and had a desire to see participation through to the end. Subjects were informed of the importance of maximal effort, especially on the graded exercise test and the A-PREP circuit. Lab staff ensured that the lab environment was consistent and encouraging throughout all exercise trials.

1.5.4 Lung Volume and Pulmonary Function Measurement Techniques

Some ventilatory parameter and pulmonary function measurements required specific techniques in order to be completed correctly. Spirometry followed the protocol and reproducibility requirements outlined by the American Thoracic Society, completed in a standing position (Miller *et al.* 2005). Inspiratory capacity was measured and interpreted according to the protocol and recommendations outlined in Johnson *et al.* (1999) and Guenette *et al.* (2013). Subjects were given instruction on the required techniques and were given practice time in order to become consistent and fulfill the requirements for each measurement.

1.5.5 Components of Ventilation

End-tidal CO_2 was used to estimate arterial PCO_2 ($PaCO_2$) following the method outlined in Stickland et al. (2013). Alveolar ventilation was estimated from $\dot{V}CO_2$ and PCO_2 (West 2012). The difference between $\dot{V}_E$ and $\dot{V}_A$ was used to determine $\dot{V}_D$ (West 2012). Estimating $PaCO_2$ may introduce error into the determination of $\dot{V}_D$. However, the method outlined in Stickland et al. (2013) is a reasonable procedure for use with healthy participants.

1.6 Definitions

1.6.1 Load Carriage

Load carriage is the transport of goods, equipment, or other items by strapping or fixing them to the body. This is typically done with a backpack or a garment made for the purpose (*e.g.* a vest or belt) in physically demanding occupations.

1.6.2 Police Duty Ensemble

Police duty ensemble is a unique form of load carriage. It combines thoracic load carriage of body armour (which is not very heavy but may be restrictive) and load carried around the waist on a duty belt. It is important to note that the mass and distribution of these components may depend not only on the police department that an officer works within, but also the individual role they may fill. The equipment in this study was representative of how the Edmonton Police Service would define police duty ensemble, as issued to a general duty police officer.

1.6.3 Alberta Physical Readiness Evaluation for Police Protocol

The Alberta Physical Readiness Evaluation for Police (A-PREP) Protocol is a work simulation of law enforcement work. It is a licensed modification of the Ontario Physical Readiness Evaluation for Police protocol, developed in Ontario. The A-PREP is used by police organizations in Alberta, Canada, in order to screen recruits for physical readiness for work (Ontario Ministry of Public Safety, Alberta Solicitor General and Public Security, Alberta Association of Chiefs of Police 2008). The A-PREP pursuit/restraint circuit was designed to stress the energy production pathways, hand grip strength, ability of an applicant to retract the arms of a suspect for handcuffing, strength of the upper body, and muscular endurance and flexibility (Gledhill and Jamnik 2007). As described by Anderson *et al.* (2001), a police officer must both get to a problem and resolve a problem. Therefore, tests of physical readiness for law enforcement work have traditionally modeled both of these aspects. A schematic of the A-PREP circuit is included in Appendix A.

1.6.4 Law Enforcement versus Policing

For the purposes of this thesis, the term law enforcement is used to refer to members of the occupations related to the enforcement of laws, public order, and public safety. Within the province of Alberta, these occupations include, but may not be limited to: peace officers; corrections officers; Canada Border Services Agency officers; Fish and Wildlife officers; and, the Alberta Sheriffs.

While also falling under the umbrella of law enforcement, policing refers to the duties taken on by sworn members of police services such as the Royal Canadian Mounted Police, the Edmonton Police Service, and the Calgary Police Service. The biggest differentiation within this thesis is that policing is used to identify officers that, within the performance of their regular duties, actively intervene in ongoing crime, respond to critical incidents, and apprehend offenders using all tactics available, including physical force.

1.6.5 Performance

For the purposes of this thesis, the term performance is used to characterize measurements that can be used to distinguish test exercise protocol endpoints that are not physiological. For example, treadmill test duration (s), peak treadmill grade (%) achieved, peak power output (W), and work simulation completion time (s) are aspects of human performance. Additionally, this term may be extended to discussions of performance in the work environment where markers of performance (*e.g.* peak running speed) are related and inter-connected to treadmill or work simulation outcomes.

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Chapter 2 – Literature Review

2.1 Literature Review Overview

Occupational physiology is a broad field encompassing many areas of interest and includes investigations into various occupational specialties. While there is a large body of literature in other occupations (*e.g.* firefighting (both structural and wildland) and military occupations) the body of literature in policing is limited. Some areas of the literature have relevance to policing (*e.g.* load carriage in other occupations). The most common articles specific to policing are located within law-enforcement journals or internal police reports, and these sources may or may not be publicly available. The aim of this literature review was to synthesize information from related areas of occupational physiology with the objective of framing the research question and hypothesis. The topics covered in this literature review include: occupational relevance; the metabolic cost of load carriage; performance; mobility; physiological strain; resting pulmonary function; the normal ventilatory response to exercise; the impact of occupational equipment on the normal ventilatory response to exercise; the impact of body armour on the normal ventilatory response to exercise; and perceptual responses. While this literature review includes many topics, it is important to consider that some topics do not have exclusive relevance to policing.

2.2 Occupational Relevance

Load carriage is common in many physically demanding occupations such as search and rescue, structural firefighting, military occupations, and policing (Taylor *et al.* 2016b). Often, occupational load carriage is in the form of a fitted backpack, but may also include garments that distribute load differently on the thorax, such as body armour or a duty belt in law enforcement. In the context of law enforcement, load carriage may also include additional items such as weapons or communications equipment (DiVencenzo *et al.* 2014). In the Edmonton Police Service, the typical mass of police officer duty equipment was approximately 8.5 ± 0.6 kg in 2005 (Pagé 2005). Currently, this mass is 10.3 ± 0.4 kg. While this mass is typical for general duty officers, speciality units (*e.g.* tactical or canine) have been reported to carry in excess of 20 kg in unique configurations (Carlton *et al.* 2013). In Canada, according to the Canada Labour Code, Part II, employers must provide protective materials, devices, equipment, and clothing that in turn, must be worn by the employee (Canada Labour Code 1985). In other words, protective equipment (and the subsequent load carriage burden of that equipment) is mandatory. This mandatory equipment reflects the minimum load for general duty patrol officers in temperate weather conditions. The addition or personal items or heavier clothing for inclement weather would only increase load above the minimum load.

A physical demands analysis for law enforcement officers in British Columbia revealed that the most common activities officers performed while on shift are sitting, standing, and walking (Anderson *et al.* 2001). While these activities take up the majority of the time on their shift, they are not necessarily time sensitive or applicable in response to a critical incident. Anderson *et al.* (2001) further divided critical incidents into controlling the problem and removing the problem. While controlling the problem, the most common activities reported by the majority of officers consulted were verbal control tactics, pulling and pushing a person, twisting and turning while controlling a person, handcuffing, and control holds (Anderson *et al.* 2001). While removing the problem, over 80% of incidents required the lifting, pulling, pushing, or dragging of a person (Anderson *et al.* 2001). During problem removal, the most difficult task encountered by officers was dragging a person (mean mass of 85 kg) up to 6 m, which 67% percent of officers deemed to be a difficult or maximal effort (Anderson *et al.* 2001).

A similar physical demands analysis conducted by the Alberta Solicitor General used between 91 supervisors, and 11 supervisor subject matter experts (supervisors with higher experience credentials) within the various police forces across Alberta to rank physical tasks based on importance, frequency, and the availability of non-physically demanding alternatives to resolve the situation (Working Committee on Police Selection and Training 2004). This physical demands analysis suggested that the ten most important physical tasks police officers in Alberta have to be able to do are: 1) discharge a firearm 2) physically restrain or control a resisting person by oneself 3) physically restrain or control a resisting person with assistance of one other person 4) fight or wrestle for an extended period of time 5) block blows or kicks in self-defence 6) avoid blows, kicks or thrown objects (*e.g.* beer bottles) 7) strike to subdue a resisting person using a baton or fist 8) force a resisting person into a vehicle, hallway, room, or cell 9) pull a resisting person from a vehicle, hallway, room or cell 10) grip objects exerting pressure or under resistance (*e.g.* flashlight, baton, clothing during altercation) (Working Committee on Police Selection and Training 2004). It should be noted that the physical tasks, run at full speed approximately 100 metres (*e.g.* foot chase, alarm response) and run at full speed – any distance, were ranked 13 and 14, respectively (Working Committee on Police Selection and Training 2004). In summary, law enforcement officers typically have sedentary shifts, punctuated with low to moderate intensity physical activity (*e.g.* patrolling a beat) and occasional maximal intensity (*e.g.* dragging a resisting suspect).

2.3 Metabolic Cost of Load Carriage

Load carriage has been shown to increase metabolic demand (Goldman and Iampietro 1962; Abe *et al.* 2004). The magnitude of the increased metabolic cost can be influenced by three major factors; load type, load placement and mass specificity. Load type is important, as metabolic cost increases with loads as simple as protective clothing for various environmental conditions or hazards (Dorman and Havenith 2009). Metabolic cost appears to be disproportional depending on what body location a load mass is placed. For example, the metabolic cost of wearing heavy boots compared to the metabolic cost of backpack load carriage was reported to be 6.4 times greater at an equivalent mass (Legg and Mahanty 1986). More recently, in a study conducted with structural firefighting equipment, it was reported that 1 kg of additional load placed on the feet elicits a change in metabolic cost that is roughly equivalent to an 8.7 kg increase of mass carried on the back (Taylor *et al.* 2012). Additionally, thoracic load carriage mass in backpacks has been observed to increase metabolic demand in a disproportionate fashion with systematic increases in pack weight (Phillips *et al.* 2016d). These findings suggest that the increased mass-oxygen cost relationship is non-linear, and more complex than originally presented by Giovani and Goldman (1971). Thus, mass specificity is especially important when discussing police equipment as the equipment is carried in very specific body locations.

2.4 Performance

Load carriage decreases performance in all exercise challenges, including: submaximal exercise, maximal exercise, and self-paced exercise (Taylor *et al.* 2012; Phillips *et al.* 2016a,b,c; Taylor *et al.* 2016a,b; Phillips *et al.* 2018a). In a physiological assessment setting, this presents as either a decrease in tolerance time at a given intensity, a reduction in intensity at the same tolerance time, or a reduction in or a failure of task performance (Beekley *et al.* 2007; Treloar and Billing 2011). Load carriage performance may vary between individuals and is hypothesized to be only moderately influenced by sex and body size, while cardiorespiratory fitness is a stronger indicator of loaded performance (Phillips *et al.* 2016a; Phillips *et al.* 2017). The performance detriment from load carriage is important to consider; a lower ability to work under load may preclude an escape from danger and contribute to the injury and death of workers (Ruby *et al.* 2003).

2.5 Mobility

No matter the discrete task in physically demanding occupations (*e.g.* dragging hose or chasing a fleeing suspect) the ability of a worker to move efficiently and effectively is crucial. The concept of mobility lacks a concise definition that spans all contexts within the literature. For the purposes of this thesis, mobility is the aptitude of a person to synthesize multiple physical competencies while rapidly moving through space in multiple planes of motion. Mobility encompasses horizontal, lateral, and vertical displacement, often involving an agility component. Mobility is the fundamental aptitude that allows a person to react to changes in physical space or to enact change on bodies in the physical space. Occupational load carriage has been shown to reduce mobility in a number of occupational settings, including: structural firefighting, wildland firefighting, military, patrol police officers, and tactical police officers (Treloar and Billing 2011; Carlton *et al.* 2013; Dempsey *et al.* 2013; Lewinski *et al.* 2015; Taylor *et al.* 2016a; Joseph *et al.* 2018; Marins *et al.* 2018). A reduction in mobility may be due to a combination of key factors, including: the mass of the equipment carried; the location on the body that the equipment is carried; and, the task performed. Loads carried on the feet are associated with larger decreases in performance than equivalent loads carried on the thorax (Legg and Mahanty 1986; Taylor *et al.* 2012). Task specificity is an important factor in determining the associated impact on mobility from load carriage, as longer duration endurance type activities (*e.g.* hiking with a pack) have fewer fast and agile movements and have a lower associated mobility cost under conditions of occupational load carriage (Keren *et al.* 1981). Conversely, short duration, power type activities (*e.g.* stop and start sprinting) bear a high requirement for speed and agility and are heavily impacted by occupational load carriage (Taylor *et al.* 2016a). The impact of occupational equipment on mobility is a key consideration when discussing the A-PREP protocol. Within the conduct of the A-PREP, a person is faced with 100m of running with 8 directional changes, two ascents and descents of a 4 foot staircase, two vaults over a 5 foot wall, two repetitions of the body control simulator that includes 9 directional changes while pushing or pulling a suspended load, two repetitions of the arm restraint simulator, and the displacement of a rescue mannequin 15 m with a change of direction. Together, the A-PREP requires participants to complete 35 agility movements while working under load, at high speed, and moving physical bodies through space. The A-PREP circuit is detailed in Appendix A. In summary, the more load a worker carries, the more distal that load is located on the extremities, and the more abrupt the change of direction, the more agility and mobility is impacted. A work simulation like the A-PREP protocol has a high mobility requirement, which means that the potential for occupational load carriage to impact mobility and subsequently performance is high.

2.6 Physiological Strain

Physiological strain is a term used to describe change in physiological variables that modulate in response to a stressor or stimulus (*e.g.* heart rate, rating of perceived exertion, core and skin temperature, minute ventilation). Throughout this thesis, discussion of physiological strain refers to the idea of using changes in selected physiological variables to describe a response to a stimulus. This should not be confused with the physiological strain index (PSI), used in thermal physiology, which uses a combination of physiological measurements to characterize the magnitude of heat stress (Moran *et al.* 1998). Load carriage is known to increase physiological strain and this may have consequences for performing work at high intensities, like reduced performance (Taylor et al. 2016b). In extremely short duration activities or activities with low exercise intensity (*e.g.* traffic control), protective clothing may have limited effect on physiological strain as metabolic demand is low. However, in longer duration activities (*e.g.* sustained moderate intensity walking) the impact of protective clothing on physiological strain may be more significant. The degree of increase in physiological strain depends on many factors, including: the type of protective equipment, the ergonomic and thermal properties of the equipment, and the activity being performed (Dorman and Havenith 2009; McLellan and Havenith 2016). Attention should be drawn to recent research that utilized a prolonged exercise model with thoracic load carriage and protective clothing. In this experiment, aspects of physiological strain (*e.g.* heart rate, perceived exertion, dyspnea) were elevated and performance (work simulation completion time) was increased with backpack load carriage and protective clothing (Phillips *et al.* 2018a). While core temperature analysis highlighted that the protective clothing did not impede thermoregulation, heart rate, perceived exertion, and perceived dyspnea were all increased (Phillips *et al.* 2018a). Importantly, the protective clothing and footwear used during this investigation had similar characteristics to police patrol uniforms and footwear. In an occupational setting, increased physiological strain may contribute to decreased total work performed or a decreased work rate for a given volume of work.

2.7 Resting Pulmonary Function

At rest, some aspects of spirometry are negatively impacted with conditions of thoracic load carriage. Reductions in the two primary measures of spirometry, forced expired volume in one second (FEV_1) and forced vital capacity (FVC), have been observed with 10 and 30 kg loads in backpacks (Muza *et al.* 1989). The reduction in these two measures is largely dependent on two factors: the mass of the load; and, tightness of fit. Load mass ranging from 15 kg up to 35 kg has been shown to reduce forced expired volume in one second by up to 6% and forced vital capacity by up to 8% (Dominelli *et al.* 2012). Tight fitting body armour has been reported to produce similar reductions in pulmonary function; likely due to the restriction that the body armour places on the expansion and movement of the chest wall (Legg 1988; Armstrong and Gay 2016). Recent load carriage literature has shown smaller reductions in some aspects of spirometry when compared with other work using lighter backpack loads; however, these reductions are more than those reported with body armour (Phillips *et al.* 2016a,c,d). These results may be due to more careful fitting procedures used in the recent research from Phillips *et al.* that ensured participants were wearing packs that comfortably accommodated exercise of various intensities and durations. These protocols included fitting to manufacturer specifications and familiarization exercise. This highlighted the importance of proper fitting and familiarization to equipment for all subjects in this police duty ensemble study, in order to elicit alterations in pulmonary function that are relevant to the proper wear and usage of the equipment in an occupational exercise setting.

2.8 The Normal Ventilatory Response to Exercise

The normal ventilatory response to exercise is a rise in minute ventilation to meet the metabolic demand of the activity. Initially, tidal volume begins to change as the human starts to use a larger portion of the total lung capacity (Sheel and Romer 2012). Modulation of tidal volume is the primary method of matching minute ventilation to metabolic demand at the onset of exercise, and subsequently as exercise intensity increases (Kearon *et al.* 1992). If exercise intensity continues to increase after tidal volume is at its largest, ventilation is then matched to oxygen demand through increased breathing frequency. Any burden on the cardiopulmonary system has the potential to alter the normal ventilatory response to exercise. In the context of occupational physiology, any potential alterations to the normal ventilatory response are important to consider because high minute ventilation has been observed to track with increased ratings of perceived exertion and perceived dyspnea and has been hypothesized to contribute to the cessation of exercise (Kearon *et al.* 1992).

2.9 The Impact of Occupational Equipment on the Normal Ventilatory Response to Exercise

Some essential occupational equipment such as heavy backpacks and the self-contained breathing apparatus may impact the normal ventilatory response to exercise (Goldman and Iampietro 1962; Abe *et al.* 2004; Beekley *et al.* 2007; Butcher *et al.* 2006; Dreger *et al.* 2006; Taylor *et al.* 2016b).

Backpacks are a form of thoracic load carriage and have been observed to alter the normal ventilatory response to exercise. During prolonged exercise with 25 kg backpacks both breathing frequency and minute ventilation were increased while concurrently, tidal volume and end inspiratory lung volume were reduced (Phillips *et al.* 2016a). These changes were accompanied by increases in perceived exercise stress and perceived dyspnea (Phillips *et al.* 2016a). The adoption of a rapid and shallow breathing pattern observed with 25 kg packs in prolonged exercise was likely a compensatory effort to mitigate the mechanical disadvantage thoracic load carriage imposed on the chest wall and to minimize the increased work of breathing associated with the backpack (Phillips *et al.* 2016a). Subsequently, this rapid and shallow breathing pattern, while compensatory, increased minute ventilation secondary to increased deadspace ventilation (Phillips *et al.* 2016a).

The utilization of protective clothing and thoracic load carriage is ubiquitous with structural firefighting. Thoracic load carriage in structural firefighting, which may or may not alter the ventilatory response to exercise outside supporting a proportional increase in oxygen uptake, includes a protective self-contained breathing apparatus (SCBA). The secondary regulator of the SCBA increases the expiratory resistive work of breathing, secondary to an increase in expiratory flow resistance (Butcher *et al.* 2006). It has also been observed that $\dot{V}O_{2max}$ is reduced during incremental treadmill exercise to exhaustion while breathing from the SCBA (Dreger *et al.* 2006).

Heavy backpacks and self-contained breathing apparatus can both alter the normal ventilatory response to exercise. It is important to differentiate the effects of these two items from the potential effects of police officer body armour. Body armour differs from backpacks in two primary ways. First, the fit of body armour is different from a backpack harness system and body armour is more encompassing of the thorax. Second, the body armour typically has a very small mass.

2.10 The Impact of Body Armour on the Normal Ventilatory Response to Exercise

Body armour worn by law enforcement officers in the United States is typically a Type-II armour, according to the classification standards set out by the United States National Institute of Justice (Taylor *et al.* 2009). This is a similar type of armour to what is used by the Edmonton Police Service (Pagé 2005). Typically, this style of body armour consists of a front and back panel, made of ballistic resistant fabric (*e.g.* Kevlar). The panels have centrally located slots for ballistic or trauma plates that provide extra protection over critical tissue areas, and the panels are secured to the front and back of the thorax with Velcro straps over the shoulders and around the stomach. An important consideration for body armour is that it needs to be tight fitting in order to provide ballistic protection. Due to the garment and fitting properties of the body armour, it is unique for two reasons: it imparts a small load on the thoracic cage and an element of chest wall restriction due to the requirement for a tight fit. The characteristics of the material and fitting properties of body armour suggest that it shares similar traits with both load carriage and chest wall restriction and in the literature there is evidence that body armour alters pulmonary function at rest (Legg 1988; Armstrong and Gay 2016). The mechanism by which body armour may alter pulmonary function at rest is likely the limitation of chest wall expansion and the reduction of both total lung capacity and inspiratory capacity. In the seminal paper examining body armour one variant of body armour closely resembles the armour used in this study and it is the lightest and least protective model examined in the study (Legg 1988). With the lightweight armour, there were very small decreases in forced vital capacity and forced expired volume in one second that did not reach significance (Legg 1988). While the available literature about body armour is helpful, caution should be used when examining its relevance to the body armour used in this study. In another study, the body armour in question was a military variant different in mass (much heavier), configuration (greater coverage), and protection level and type (fragmentation protection and ceramic plates for larger calibre small arms protection) (Armstrong and Gay 2016).

Chest strapping, which constricts the thorax with various types of bands, may appear to be a valid model for the effects of body armour as body armour is typically tightened to the thorax with Velcro bands. Chest strapping has been reported to contribute to diaphragmatic fatigue, increased ratings of dyspnea, and reduced exercise performance (O'Donnell *et al.* 2000; Tomczak *et al.* 2011). While potentially related, caution should be used when comparing body armour closely with chest strapping. In the previously mentioned chest strapping studies, the methods of chest strapping are much less flexible and pliable than the elastic and Velcro straps used to secure body armour to the thoracic cage and this could lead to a speculative overestimation of the effect of the body armour on pulmonary function.

While the potential alteration of resting pulmonary function due to body armour is an important consideration, it may not be occupationally relevant. When considering the larger context of law enforcement work, the primary concern with body armour is the potential for an alteration to the normal ventilatory response to exercise. Previous work in our laboratory has examined the metabolic cost of police duty equipment, and highlighted that, compared to an unloaded control, breathing frequency is elevated while tidal volume is reduced at peak exercise (Pagé 2005). If the body armour impacts the expansion of the thoracic cage above a certain tidal volume, then compensation must occur in other components of ventilation. Logically, if thoracic cage expansion is limited then minute ventilation would increase in order to maintain alveolar ventilation as dead space ventilation rises. To determine if this is occurring, an in-depth analysis of the components of ventilation with police issue body armour must be completed, and this is not reported in the literature.

2.11 Perception of Exertion

It is well documented that as metabolic demand increases, the rating of perceived exertion also increases, following a similar pattern of change to heart rate (Borg 1982). Recently, it has been suggested that in a load carriage model, increased perceived exertion and dyspnea may be secondary to increased minute ventilation (Phillips *et al.* 2016a). If increased minute ventilation, perceived exertion, and dyspnea are related and may contribute to the cessation of exercise, their interaction is of crucial importance in a police context.

2.12 Summary

The general duty police ensemble is a required aspect of policing. Various forms of load carriage, including body armour, have been observed to increase metabolic cost, physiological strain, and perceived exertion and dyspnea during exercise. Load carriage and body armour have been shown, independently and in combination, to decrease performance, mobility, and resting pulmonary function. Synthesized evidence from the study of both policing and other occupations suggested that police duty ensemble could impact the normal ventilatory response to exercise. Furthermore, there is strong evidence that occupational ensembles reduce job-task performance.

In order to determine how police duty ensemble would impact the components of the ventilatory response to exercise and work simulation performance, a detailed examination was required.

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Chapter 3 – The Experiment

"The Effect of General Duty Police Ensemble on Graded Exercise and Simulated Work Performance"

3.1 Introduction

Police officers frequently engage in physically demanding work that includes use of specialized equipment and protective clothing. Occupational load carriage is known to increase metabolic demand (Goldman and Iampietro 1962) and the magnitude of increase depends primarily on load mass and location. Metabolic cost increases disproportionately with increased load mass above 30 kg (Phillips *et al.* 2016d), and some body locations elicit a higher metabolic cost than others for the same mass (Legg and Mahanty 1986; Taylor *et al.* 2012). Despite increased metabolic demand due to load carriage, the reduction of physiological maxima such as $\dot{V}O_{2peak}$ is small with loads up to 26 kg (Louhevaara *et al.* 1995; Taylor *et al.* 2012; Phillips *et al.* 2016a,b). However, load carriage does result in a substantial reduction in exercise performance (*e.g.* treadmill test duration) (Louhevaara *et al.* 1995; Taylor *et al.* 2012; Dempsey *et al.* 2013; Phillips *et al.* 2016a,b,c). Any possible effects on physiological responses or exercise performance due to load carriage could have important implications for police officers.

As described by Anderson *et al.* (2001) a police officer must both get to a problem and resolve the problem. Officers must be highly mobile and responsive on foot as they navigate directional changes and obstacles in the environment as well as strong enough to manage a non-compliant suspect. These challenges form the framework for physical aptitude tests that simulate essential elements of police work (Jamnik et al. 2013). Two examples of these tests are the Physical Abilities Readiness Evaluation (PARE), used by the Royal Canadian Mounted Police (Bonneau and Brown, 1995), and the Alberta Physical Readiness Evaluation for Police (A-PREP), used by police services in Alberta (Gledhill and Jamnik 2007; Gumieniak *et al.* 2013). Various occupational clothing ensembles are known to reduce performance on individual mobility tasks such as acceleration, speed, agility, and jump height (Carlton *et al.* 2013; Dempsey *et al.* 2013; Joseph *et al.* 2018; Taylor et al. 2016). Work simulations in law enforcement, like the RCMP Physical Abilities Readiness Evaluation (PARE), involve a series of tasks that typically have both a speed and mobility component. Logically, if load carriage is known to reduce performance during other exercise challenges, the duty ensemble may alter performance in work simulations (*e.g.* increased completion time). Compared to a control condition consisting of police clothing, adding the protective equipment (*e.g.,* duty belt, weapons) parts of the ensemble decreased performance by about 7% during a test of occupational fitness (Marins *et al.* 2018).

The intensity of exercise in general duty police work can range from light (*e.g.,* patrolling a beat) to maximal (*e.g.,* apprehending a fleeing suspect), and is completed while wearing job-specific equipment. Standard issue equipment for general service police officers consists of a uniform, boots, duty belt with required small equipment (*e.g.* ammunition, handcuffs), weapons, soft body armour, and communications equipment (Dempsey *et al.* 2013). Some body armour has been reported to alter pulmonary function at rest (Legg 1988; Armstrong and Gay 2016). It is possible that these changes are similar to those found with chest wall strapping that may contribute to diaphragmatic fatigue, increased dyspnea, and reduced performance during exercise (O'Donnell *et al.* 2000; Tomczak *et al.* 2011). Logically, if thoracic cage expansion is limited by of body armour, minute ventilation may be constrained during heavy exercise. Police duty ensemble has been previously reported to increase metabolic demand during submaximal exercise and reduce peak treadmill performance, however the effects on the components of ventilation are unknown (Pagé *et al.* 2005; DiVencenzo *et al.* 2014).

The purpose of Part I of this study was to examine the physiological responses during submaximal and maximal graded treadmill exercise with police duty ensemble. The purpose of Part II was to examine the impact of police duty ensemble on job-related performance using a recognized work simulation of police work.

It was hypothesized that the physiological response to submaximal exercise would be altered due to load carriage, however the increases in oxygen consumption, ventilation, and heart rate would not be fully explained by the added mass. Furthermore, at peak exercise, we hypothesized that the duty ensemble would lead to compensatory changes in breathing pattern (reduced tidal volume and increased breathing frequency) in order to maintain alveolar ventilation. It was hypothesized that during the work simulation model, completion time would be greater in the loaded conditions but, markers of physiological strain, such as heart rate and perceived exertion, would be similar.

3.2 Methods

3.2.1 Subjects and Design

This study was conducted with a convenience sample of 25 healthy, physically active, non-smoking males (n=15) and females (n=10). This exploratory investigation included males and females because the Edmonton Police Service employs males and female officers. However, the study did not explore questions related to sex differences. The sample size was sufficient to achieve statistical power for all primary outcomes and is similar to previously published work from our laboratory with similar primary outcomes and methodology (Phillips *et al.* 2016a,b,c,d). All subjects provided written informed consent prior to participation. The study was approved by the appropriate institutional research ethics board. The physical characteristics of the participants were similar to recruits to the Edmonton Police Service (Table 3-1) (S.J. Lemelin, personal communication, 2018).

This study was conducted in two parts, occurring over six visits to the laboratory. Part I was designed to examine the impact of the duty ensemble on selected cardiopulmonary responses to graded treadmill exercise. Part I consisted of Day 1: Familiarization; and, Days 2 and 3: Graded exercise tests. Part II was designed to examine the impact of the duty ensemble on performance time and physiological strain during a recognized work simulation. Part II consisted of Day 4: Familiarization to the Alberta Physical Readiness Evaluation for Police (A-PREP) circuit and practice of the circuit; Day 5: Practice of the circuit; and, Day 6: Experimental trials on the circuit. All subjects completed Part I. One male and one female participant were unable to complete Part II due to scheduling conflicts. Sample sizes for specific analyses are indicated where applicable.

There were three experimental conditions: physical training (PT); weight belt (WB); and, police duty ensemble (PDE). Physical training included undergarments, t-shirt, running shoes, and shorts. The WB condition was the same as PT with the addition of a 7.5 kg weighted belt (Rejo Sporting Goods Ltd., Brantford, ON, Canada). This belt, worn around the waist, is intended to simulate the load of police equipment when testing applicants to the police service (Gledhill and Jamnik 2007). The police duty ensemble consisted of undergarments, concealable body armour (Revolution, Armor Express, Central Lake, MI, USA), patrol uniform (Prestige/Distinction Short Sleeve Shirts/Pants, Elbeco, Reading, PA, USA), duty belt with required small equipment (*e.g.,* ammunition, handcuffs) and simulated weapons (Deluxe Duty Belt [inner/outer], Uncle Mike's Tactical, Overland Park, KS, USA) and boots (Original SWAT Classic 9", Georgetown, ON, Canada). The simulated weapons were faithful scale and mass replications of the Edmonton Police Service standard issue sidearm (Glock 22, Glock Inc., Smyrna, GA, USA) and Taser (X2, Axon, Scottsdale, AZ, USA). Two conditions, PT and PDE, were used in Part I while all three conditions were studied in Part II.

3.2.2 Familiarization

Each subject completed a comprehensive familiarization protocol that included duty ensemble fitting, practice of experimental measurement techniques (spirometry, inspiratory capacity, exercise and breathing stress perceptual scales), and a 10-minute bout of exercise on a treadmill in the PDE condition. Following the treadmill exercise, each subject confirmed that all clothing and equipment were fitted properly for challenging exercise. If part of the ensemble was altered, the subject would repeat the exercise protocol to ensure proper fitting of the clothing and equipment during exercise. Subsequently, the position of all fitment adjustments was recorded to maintain consistent fit throughout the study. All fitting protocols followed manufacturer's specifications and additionally for the body armour, the recommendations of the United States National Institute of Justice (Sabol *et al.* 2014).

3.2.3 Part I, Graded Exercise Tests

In Part I, conducted over two days, subjects completed a graded exercise test to exhaustion in one of two clothing conditions previously described (PT and PDE) in a balanced, randomized order. The treadmill (Standard Industries, Fargo, ND, USA) protocol consisted of walking at 93.9 $m \cdot min^{-1}$ starting at 0% grade with 2% increases in grade every two minutes. The stage at 4% grade was extended to six minutes duration to allow measurement of steady-state responses during submaximal exercise. The mean responses from the last four minutes of this extended stage were reported as steady-state, which was defined as change of less than 100 $ml \cdot min^{-1}$ in $\dot{V}O_2$ during the four minute period. Upon completion of this phase, the 2% increases in grade every two minutes were resumed until volitional exhaustion. All treadmill tests were followed by a standardized cool-down period before the subject dismounted the treadmill.

Measurements taken during Part I included heart rate, expired gas, inspiratory capacity, and mouth pressure. Rating of perceived exertion and rating of perceived dyspnea were recorded at the end of each stage. Before and after exercise subjects completed resting forced vital capacity maneuvers following American Thoracic Society (ATS) criteria (Miller *et al.* 2005). Due to the load carriage and body position during exercise, the protocol was modified slightly with spirometry completed standing upright with minimal forward lean. The results of the pre- and post-exercise spirometry in the physical training (PT) condition were used in order to screen for normal pulmonary function and detect exercise-induced bronchoconstriction (EIB). At least 24 hours separated the treadmill tests to allow recovery.

3.2.4 Perceptual Responses

Modified Borg scales were used to quantify psychophysical responses during both Parts I and II (Borg 1982). Within this study, rating of perceived exertion was defined, for our subjects, as the intensity of exercise stress. Dyspnea was defined for our subjects, as the intensity of breathing stress. Subsequently, the categorical-ratio scales were titled “Exercise Stress” and “Breathing Stress”. The scales were anchored from 0 to 10, such that 0 represented “no exercise or breathing stress” and 10 represented “maximal exercise or breathing stress”. The researcher prompted the participant by asking, “how would you rate your exercise [or, breathing] stress?” The scales were printed in large text on signboards and placed in front of the treadmill and in a strategic location on the circuit path for easy reference. The methodology used was consistent with recently published work from our laboratory (Phillips *et al.* 2018b).

3.2.5 Cardiorespiratory Measurement Procedures

Expired gas data were collected using a two-way, non-rebreathing valve (Hans Rudolph, Kansas City, MO, USA) and analyzed with a metabolic measurement system (TrueOne, ParvoMedics, Salt Lake City, UT, USA). The gas analyzers and pneumotachs were calibrated before each test and the stability of gas analyzer calibration was verified immediately after each test. Gas analyzers were acceptably stable (defined as a change in F_EO_2 between pre-test and post-test of > 0.05) and no data required correction. Heart rate (HR) was measured continuously using telemetry, and was recorded during the last ten seconds of each stage of exercise completed (Polar Beat, Electro, Lachine, QC).

End-tidal carbon dioxide was sampled through a small port near the mouthpiece on the two way, non-rebreathing valve which was then connected to a drying line. $ETCO_2$ was measured using a carbon dioxide analyzer (R-1 pump, P-61B sensor, CD-3A CO_2 analyzer, AEI Technologies, Naperville, IL, USA) and recorded using a data acquisition system (Powerlab 8/35, ADInstruments, NSW, Australia). These data were displayed for analysis on a laptop computer and conversion to $P_{ET}CO_2$. The CO_2 gas analyzer was calibrated with a standard gas mixture before exercise and the calibration was verified following every test. The gas analyzer calibration was stable throughout all tests.

End-tidal CO_2 was utilized to estimate arterial PCO_2 (P_aCO_2) as per the method outlined in Stickland *et al.* (2013). Alveolar ventilation was estimated from $\dot{V}CO_2$ and PCO_2 (West 2012). The difference between $\dot{V}_E$ and $\dot{V}_A$ was used in order to determine $\dot{V}_D$ (West 2012). Estimating $PaCO_2$ may introduce error into the determination of $\dot{V}_D$. However, the method outlined in Stickland et al. (2013) has been previously used with healthy participants (Phillips *et al.* 2016a,c,d).

3.2.6 Inspiratory Capacity

Inspiratory capacity maneuvers were completed at rest, before, and during exercise. For baseline, the subject stood on the treadmill with the grade at 0% to collect inspiratory capacity data. During exercise, inspiratory capacity was measured within the last 15 seconds of each stage of exercise. Inspiratory capacity was measured using an inspiratory pneumotach (Hans-Rudolph, Kansas City, MO, USA) connected to the two way, non-rebreathing valve. The inspiratory pneumotach was calibrated before every exercise trial according to manufacturer specifications. Inspiratory capacity measurements were completed following the same procedures as previously described (Phillips *et al.* 2016a,b; Phillips *et al.* 2018a).

3.2.7 Mouth Pressure

Mouth pressure was measured within the last thirty seconds of each stage of exercise with the use of a small port, near the mouthpiece, on the two way, non-rebreathing valve connected to a differential pressure transducer (DP15, Validyne, Northridge, CA) with surgical tubing. The pressure transducer signal was amplified using a demodulator (CD280, Validyne, Northridge, CA) and recorded using a data acquisition system (Powerlab 8/35, ADInstruments, NSW, Australia). These data were displayed for real time monitoring on a lap top computer, and stored for later analysis. The peak inspired and expired pressures used for analysis were the mean of five consecutive respiratory cycles. Peak inspired and expired pressures were used to calculate pressure swing (difference between peak positive and negative pressures). The pressure transducer was calibrated before and verified following every test, using a ±5 cmH_2O water column. Measurement of mouth pressure followed procedures previously described by Eves *et al.* (2005) and Butcher *et al.* (2006).

3.2.8 Part II, Alberta Physical Readiness Evaluation for Police Circuit Protocol

The Alberta Physical Readiness Evaluation for Police (A-PREP) is a pursuit and restraint test circuit that simulates a police officer chasing and apprehending a suspect. The circuit contains high intensity running (100 m) on an oval shaped course that includes 35 changes of direction, elevation, and tasks. These tasks include mobility challenges (*e.g.* stairs and a wall obstacle) and resistance exercises at two stations. One station requires pushing and pulling against a resistive load while moving through a prescribed arc. This simulates grappling with and controlling a resisting suspect. The second station simulates gripping and retracting the arms of a resisting suspect for handcuffing. The final component involves dragging a 68 kg rescue mannequin a distance of 15 m. A schematic of the A-PREP circuit is included in Appendix A. The elapsed time to complete all three components is the test score (Gledhill and Jamnik 2007; Gumieniak *et al.* 2013). This part of the study consisted of completing the A-PREP test circuit in the three experimental conditions as previously described. Standardized equipment for the A-PREP circuit was provided by the Edmonton Police Service.

To begin Part II, subjects were introduced to the A-PREP circuit. The familiarization was standardized and completed in the PT condition in a ‘walk-through’ format that allowed the subjects to get a feel for the equipment and to ask questions. Following the informative portion, subjects completed through the circuit at a self-selected pace to become comfortable with the sequence of events and to develop an appreciation for the work involved. Next, on the same day, subjects began to practice the A-PREP circuit in order to minimize the effects of learning on performance time (Boyd *et al.* 2015). The practice session consisted of completing the circuit in all three conditions, in random order, with a standardized warm-up before and recovery after each condition. The warm-up was task specific and conducted in a similar fashion to the warm-up described by Boyd *et al.* (2015). Participants completed a warm-up for each condition in the selected clothing ensemble. The standardized recovery consisted of 20 minutes of cycling at a self-selected intensity between 80-100 W. This recovery time and intensity was selected based on evidence in the literature regarding sufficient recovery time and activity to minimize performance variance in repeated bouts of high-intensity exercise (Ainsworth *et al.* 1993; Menzies *et al.* 2010). The standardized recovery protocol was confirmed to be effective with extensive pilot work. The practice sessions allowed subjects to become accustomed to having their heart rate recorded and to report perceptual responses at specific points during the circuit, and most importantly, to adopt optimal pacing strategies. Each subject completed two practice circuits in each experimental condition over the two practice days. During these practice sessions, subjects were encouraged to ensure that they gave their best possible effort. Practice sessions were separated by at least 24 hours rest.

On the third experimental day, subjects completed the A-PREP circuit once in each experimental condition. The order was assigned randomly, but balanced between subjects to eliminate the possibility of an order effect. Experimental trials were bracketed by the same standardized warm-up and recovery as in practice. Performance time and markers of physiological strain (heart rate and perceptual responses) were measured in each condition in order to determine the effect of the police duty ensemble on performance.

3.2.9 Data Analysis

Data are presented as mean ± standard error (SE) unless otherwise indicated. Paired t-tests were used to detect differences in key dependent variables for peak exercise responses between conditions in Part I (two-tailed). Two-way, repeated measures analysis of variance (ANOVA) was used to compare submaximal exercise responses during steady-state and at selected intensities between conditions in Part I. One-way, repeated measures analysis of variance (ANOVA) was used to compare the effect of both the weighted belt and duty ensemble on key dependent variables during the work simulation in Part II. All statistical analyses were performed using Sigma Plot Software version 13.0 (Systat Software Inc., Chicago, USA). The criterion for statistical significance was set *a priori* at $p<0.05$. For all ANOVA tests, where a significant main effect was detected the Holm-Sidak post-hoc test was used to locate differences. In cases where the p-value was close to the criterion, other information (*e.g.* actual p-value, effect size, *F*-score) has been provided to assist the reader. All reported effect sizes were calculated using Cohen's *d* (Cohen 1988).

3.3 Results

3.3.1 Part I, Steady-state Exercise

The physiological responses to steady-state exercise are displayed in Table 3-2. Oxygen consumption was significantly higher in the PDE condition when compared to PT ($p<0.05$). When normalized to total mass (body mass + duty ensemble), oxygen consumption was significantly higher during this phase of the treadmill test ($p<0.05$). Minute ventilation was significantly increased in the PDE condition compared to PT ($p<0.05$). The ventilatory equivalent to oxygen consumption was significantly increased between the PDE condition and PT ($p<0.05$). Heart rate was significantly higher when comparing the PDE condition to PT ($p<0.05$). Ratings of perceived exertion and dyspnea were significantly higher between the PDE condition and PT ($p<0.05$; $p<0.05$).

3.3.2 Part I, Components of Ventilation at Selected Exercise Intensities

The physiological responses to selected exercise intensities during the graded exercise tests are displayed in Figure 3-1 and 3-2. The selected exercise intensities were baseline, 40, 60, 80

$\%\dot{V}O_{2peak}$, and peak exercise. Figure 3-1 details minute ventilation, $P_{ET}CO_2$, alveolar ventilation, and deadspace ventilation at the selected exercise intensities. Alveolar ventilation was maintained at all selected exercise intensities. Figure 3-2 details changes in operating lung volume (absolute volume and %FVC) at the same selected exercise intensities. While differences in operating lung volume were observed between conditions when examining absolute operating lung volume (L), there were no differences in normalized operating lung volume (%FVC) between conditions.

3.3.3 Part I, Peak Exercise

The peak physiological responses are displayed in Table 3-3. Peak absolute $\dot{V}O_2$ between PT and PDE conditions was not different. When normalized to total mass carried (body mass + duty ensemble), $\dot{V}O_{2peak}$ was reduced in PDE ($p<0.05$). Minute ventilation, tidal volume, breathing frequency, $P_{ET}CO2$, and mouth pressure swing were unchanged during peak exercise between conditions ($p>0.05$). There were no significant differences in perceptual responses at peak exercise. In the PDE condition peak power output, test duration, and peak treadmill grade were significantly lower compared to the PT condition ($p<0.05$).

During pre-exercise spirometry there were small but significant reductions in FEV_1 (forced expired volume in one second) (Mean ± SE 4.33 ± 0.15 [PT] vs. 4.19 ± 0.15 [PDE]; $p<0.05$) and FVC (forced vital capacity) (Mean ± SE 5.35 ± 0.20 [PT] vs. 5.15 ± 0.20 [PDE]; $p<0.05$) with no change in FEV_1/FVC ratio (Mean ± SE 81 ± 1 [PT] vs. 82 ± 1 [PDE]; $p>0.05$) and PEFR (peak expiratory flow rate) (Mean ± SE 9.03 ± 0.43 [PT] vs. 8.90 ± 0.42 [PDE]; $p>0.05$) (n=25). These reductions could be characterized as a mild restrictive effect.

3.3.4 Part II, Alberta Physical Readiness Evaluation for Police Circuit Protocol

In the A-PREP work simulation, performance time was unchanged in the WB condition when compared with PT and increased in PDE compared to both PT and WB ($p>0.05$; $p<0.05$). In the A-PREP circuit protocol, between all conditions there was no significant difference in heart rate ($p>0.05$). Perceived dyspnea was increased in the PDE condition compared to PT and WB ($p<0.05$) (Table 3-4).

In addition to randomization, the order of testing conditions on all circuit days (both practice and experimental) was also balanced to eliminate any condition testing order/performance time interaction effects. In order to confirm this, all experimental trials were compared with two-way, repeated measures ANOVA, independent of condition, to confirm the efficacy of balanced randomization. There was no significant difference between test one, two, and three in the experimental day, confirming that independent of condition, the balanced randomization was effective ($p>0.05$).

3.4 Discussion

3.4.1 Major Findings

The major findings from this study are fourfold. First, the duty ensemble increased all measured physiological parameters ($\dot{V}O_2$, $\dot{V}_E$, heart rate, perceived exertion and dyspnea) during the steady-state phase on the treadmill, with the increase in oxygen consumption not explained by the additional mass alone. Second, when compared to PT, peak exercise responses were unchanged during treadmill tests to exhaustion with the duty ensemble. Third, despite similar peak physiological responses, exercise duration was reduced by 15 ± 1%, peak treadmill grade was reduced by approximately 3.7 ± 0.2%, and power output (W) was reduced by 9 ± 1%. Fourth, performance time on the A-PREP circuit was unchanged from PT by adding the weight belt, however with the PDE condition, completion time was significantly longer compared to both PT and WB. Overall, police duty ensemble increased physiological strain, which reduced peak exercise performance and reduced performance during simulated work.

3.4.2 Steady-state Phase

During steady-state exercise on the treadmill, all physiological responses were higher in PDE when compared to PT. The PDE added 10.3 ± 0.4 kg of mass (14 ± 2% body mass) and would normally be considered relatively light load carriage. The metabolic cost of the duty ensemble was 31 ± 2 ml per additional kg of mass. This is substantially different than the 17 ml per additional kg of load that is commonly expected with load carriage under ideal conditions where the total mass is supported by the legs and includes protective clothing, equipment, and added loads (Taylor *et al.* 2016a). A comparison of values of oxygen cost per additional kg of load from selected experiments is shown in Figure 3-3. Direct comparison of these values is not prudent due to differences in exercise protocols and types of load. However, these data are suggestive of a 'specificity' principle in the $\dot{V}O_2$ response during similar exercise (treadmill walking at moderate speed and grade) with loads of varying type and mass. This would suggest that the observed oxygen cost (1.84 $L \cdot min^{-1}$) with the PDE was not due to mass alone and would not likely be accounted for by correction factors present in some predictive equations (*e.g.*, terrain type) (Givoni and Goldman 1971). These factors include, but are not limited to: load location, interaction of clothing layers, and occupational footwear. Footwear with greater mass than running shoes is known to increase metabolic demand and reduce performance, primarily due to load location (Legg and Mahanty 1986; Taylor *et al.* 2012). The same model of footwear used in this study was previously shown to reduce performance and increase physiological strain when worn in combination with wildland firefighting coveralls during a prolonged exercise trial (Phillips *et al.* 2018a).

The 'hobbling effect' is a term that has been used to describe the interaction between layers of clothing (Tietlebaum and Goldman, 1972; Duggan, 1988) and this concept is helpful when examining the effect of clothing in the PDE condition. In the ensemble, the person is wearing at least one layer over their undergarments on the lower body (uniform), and at least two layers over their undergarments on the upper body (uniform and body armour). Additionally, while not a full layer of clothing covering a large body surface area, the duty belt could contribute to the hobbling effect as it shifts in place during vigorous exercise.

A somewhat crude but useful method for estimating changes in efficiency is to examine net oxygen cost (ml) per Watt during treadmill exercise, having accounted for baseline metabolic cost. This analysis is displayed in Table 3-2 and 3-3 and provides evidence for reduced efficiency in the PDE. Subjects reported that movement about the lower extremities was more difficult with the duty ensemble during treadmill exercise. Future investigations could focus on a fractionation of the relative burden of each item of the duty ensemble or combining kinematic analysis with investigations of economy. The combination of load mass, load location, and reduced efficiency are likely the most meaningful contributors to the 0.32 $L \cdot min^{-1}$ increase in oxygen consumption with PDE when compared to PT during the steady-state phase. The findings from previous research as presented in Figure 3-3 and the findings from this investigation provide evidence to suggest that the metabolic cost of load carriage is highly specific and that attempting to predict metabolic cost based on load mass may be erroneous. This increase in metabolic cost has implications for policing as low exertion – long duration work (*e.g.* walking continuously during patrol duties, 30 min or longer at a time) is identified within the minimum levels of the physical requirements for the patrol constable in Alberta (Working Committee on Police Selection and Training 2004).

3.4.3 Maximal Exercise Tests

At peak exercise, there were no significant differences in physiological or perceptual variables (*e.g.* $\dot{V}O_2$, $\dot{V}_E$, Rating of Perceived Exertion) between PT and PDE conditions. In addition, analysis of the components of ventilation at selected intensities in the graded exercise tests was conducted. The aim of this sub-analysis was to determine whether detectible compensatory adjustments in the components of ventilation were made throughout the selected exercise intensities in order to maintain alveolar ventilation. If this had occurred, estimating alveolar ventilation alone would have masked any major compensatory changes. Throughout the selected intensities, alveolar ventilation and $P_{ET}CO_2$ were maintained (F=0.024 and <0.001, respectively), while deadspace ventilation was increased with duty ensemble during peak exercise only (Figure 3-1) ($p<0.001$). These findings suggest that any burden induced on the cardiopulmonary system by the duty ensemble was compensated for appropriately during incremental exercise to exhaustion on a treadmill. The resting spirometry results observed are consistent with those reported in Legg (1988) for lightweight body armour and are suggestive of a restrictive pattern. However, analysis of the components of ventilation and operating lung volume at selected exercise intensities provides evidence that alterations to resting spirometry did not translate to impaired ventilatory responses during exercise with the duty ensemble (Figure 3-1 and 3-2).

Despite the unchanged physiological variables at peak exercise, there was a reduction in performance time (15 ± 1%) and power output (W) (9 ± 1%). While the PDE added 10.3 ± 0.4 kg of mass, the reduction in peak power output with PDE is similar to that seen with thoracic load carriage (in addition to a PT condition) of 20.4 kg in a fitted backpack (9%) (Phillips *et al.* 2018a). In absolute terms, peak treadmill grade was reduced 3.7 ± 0.2% with PDE. Although $\dot{V}O_{2peak}$ was unaffected, the additional metabolic demand of the PDE reduced the amount of $\dot{V}O_2$ available for locomotion, contributing to the reductions in power output and performance.

3.4.4 Simulated Work Performance

Performance time on the circuit was unchanged between the PT and WB conditions ($p=0.053$; Cohen's $d=0.17$). However, completion time was increased in the PDE condition when compared to both the WB (6.5 s) and PT conditions (9 s) ($p<0.001$; Cohen's $d=0.39$ and 0.53, respectively). This may be explained by several factors, including: the load mass; load location; and, the previously discussed 'hobbling effect'. Additionally, these factors should be considered when applied to a situation where a person is required to complete tasks involving agility and rapid change of direction. The aim of the weighted belt was to simulate the effects of the full ensemble during the testing of physiological readiness for police work. Despite these intentions, our results show that adding this central load failed to have a systematic effect on performance. Some subjects posted the same times in the PT and WB conditions. In contrast, all performance times in PDE were slower than either WB or PT, which demonstrated that the full ensemble decreased performance where the belt did not.

3.4.5 Implications and Limitations

This investigation has revealed that with this police duty ensemble there were no significant consequences for the cardiopulmonary system at maximal exercise. Through all facets of our investigation the PDE increased the physiological and perceived strain during work at moderate intensities and decreased peak performance. Peak physiological variables were unchanged but the additional mass of PDE was not sufficient, in isolation, to explain why performance was so encumbered. In the case of treadmill performance the load mass, load location, and 'hobbling effect' might help explain the effects on peak and moderate exercise performance and physiology. In the case of the work simulation, the only factor in addition to the PT condition is the additional mass in the form of a belt only (WB). This belt does not add clothing layers or distribute any mass to the feet. As observed in this experiment, the weight belt did not have the same effect on performance and perceptual responses as the complete PDE.

Finally, it appears that the effects of clothing and load carriage on exercise performance are highly specific to the situation. Caution should be used when interpreting these results and trying to apply them to different orders of dress in various police forces, differing law enforcement occupations, or different work simulations. It should be noted that specialty occupations in policing have different equipment specifications and complete different law enforcement tasks when compared to general duty patrol officers. Future research could examine the impact of other examples of duty ensemble (*e.g.* used by canine and tactical officers) and the impact of duty ensemble during other exercise challenges (*e.g.* prolonged exercise at ventilatory threshold) to determine if the impact on the cardiopulmonary system differs.

3.5 Conclusion

The results of this study demonstrated the impact of police duty ensemble during submaximal exercise, a graded treadmill exercise challenge, and simulated work performance. The increased metabolic cost observed with the duty ensemble was not proportional to the added mass of the duty ensemble at 10.3 ± 0.4 kg. The results are likely confounded by an interaction effect from a combination of load placement, multiple clothing layers, and occupational footwear. This is particularly impactful during tasks involving agility and explosive movement. The results of this study highlight the importance of using faithful representations of occupational equipment when testing physiological readiness for work, as the weight belt simulation does not effectively replicate the distribution of load or the current mass of duty ensemble. Further, these results suggest that simulating police duty ensemble with a weight belt may be no more effective than testing participants in their basic exercise clothing.

Chapter 3 - References

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Table 3-1. Mean (±SD) characteristics of study participants (Upper, n=25) and recruits to the Edmonton Police Service between 2015 and 2018 (Lower, n=307).

Characteristic	Mean	SD	Range
Study Subjects: 15 males, 10 females.			
Age (y)	26	5	21-39
Height (cm)	175.4	7.5	162.0-189.0
Mass (kg)	74.9	12.8	57.4-113.6
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	3.63	0.88	2.28-5.30
$\dot{V}O_{2peak}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)*	48.1	7.7	32.5-61.7
Police Recruits: 228 males, 79 females.			
Age (y)	28	5	20-48
Height (cm)	177.0	8.7	149.9-200.7
Mass (kg)	80.4	13.6	53.2-130.9
$\dot{V}O_{2peak}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)**	51.3	1.8	43.6-64.6

*Measured during treadmill tests

**Predicted from Leger 20 m shuttle run score.

Table 3-2. Mean (±SE) physiological responses in physical training (PT) and police duty ensemble (PDE) conditions during steady-state, submaximal treadmill exercise (93.9 $m \cdot min^{-1}$, 4% grade). (n=25)

Variable	PT	PDE	Difference (%)
$\dot{V}O_2$ ($L \cdot min^{-1}$)	1.52 (0.06)	1.84 (0.05)*	+21% (2%)
$\dot{V}O_2$ ($ml \cdot kg_{totalmass}^{-1} \cdot min^{-1}$)	20.2 (0.4)	21.5 (0.3)*	+6% (2%)
$\dot{V}_E$ ($L \cdot min^{-1}$)	36.7 (1.4)	46.4 (1.6)*	+26% (3%)
$\dot{V}_E/\dot{V}O_2$	24 (1)	25 (1)*	+4% (2%)
Oxygen cost per Watt (ml)	26.0 (0.7)	28.9 (0.4)*	+11% (4%)
Heart rate ($beats \cdot min^{-1}$)	123 (3)	138 (4)*	+12% (1%)
Perceived exercise stress (0-10)	2.3 (0.6)	2.7 (0.2)*	+17% (8%)
Perceived dyspnea (0-10)	2.3 (0.2)	2.7 (0.2)*	+17% (10%)

* $p<0.05$ compared to PT.

Table 3-3. Mean (±SE) peak exercise data in physical training (PT) and police duty ensemble (PDE) conditions. (n=25)

Variable	PT	PDE
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	3.64 (0.18)	3.59 (0.17)
$\dot{V}O_{2peak}$ ($ml \cdot kg_{totalmass} \cdot min^{-1}$)	48.1 (1.5)	41.6 (1.3)*
$\dot{V}_E$ ($L \cdot min^{-1}$)	134.9 (6.7)	136.9 (7.5)
Breathing frequency ($breaths \cdot min^{-1}$)	50 (2)	53 (2)
Tidal volume (L)	2.73 (0.19)	2.64 (0.17)
Pressure of end-tidal CO_2 (mmHg)	32.08 (0.63)	32.70 (0.64)
Mouth pressure swing (cmH_2O)	10.5 (1.0)	9.4 (0.6)
Respiratory exchange ratio	1.10 (0.01)	1.13 (0.01)*
Heart rate ($beats \cdot min^{-1}$)	190 (2)	189 (2)
Perceived exercise stress (0-10)	9.2 (0.1)	9.1 (0.2)
Perceived dyspnea (0-10)	8.9 (0.2)	9.0 (0.2)
Treadmill time (s)	1463 (36)	1247 (32)*
Peak treadmill grade (%)	19 (1)	15 (1)*
Peak power output (W)	221 (10)	203 (11)*
Oxygen cost per Watt (ml)	15.0 (0.2)	16.2 (0.3)*

* $p<0.05$ compared to PT.

Table 3-4. Mean (±SE) performance time and physiological strain data on the Alberta Physical Readiness Evaluation for Police circuit in three experimental conditions: PT, physical training; WB, 7.5 kg weighted belt; and, PDE, police duty ensemble. (n=23)

	PT	WB	PDE	Difference (%)	
Performance				*PT vs. WB*	*PT vs. PDE*
Circuit time (s)	89.0 (3.0)	91.5 (2.9)	98.0[ab] (3.8)	+3% (1%)	+10% (1%)
Strain					
Heart rate (bpm)	167 (3)	168 (2)	170 (3)	+1% (1)	+2% (1)
Perceived exercise stress (0-10)	9.0 (0.2)	9.0 (0.2)	9.3 (0.2)	+0% (1%)	+3% (2%)
Perceived dyspnea (0-10)	8.9 (0.2)	8.9 (0.2)	9.3[ab] (0.2)	0% (1%)	+4% (2%)

[a] $p<0.05$ compared to PT; [b] $p<0.05$ compared to WB.

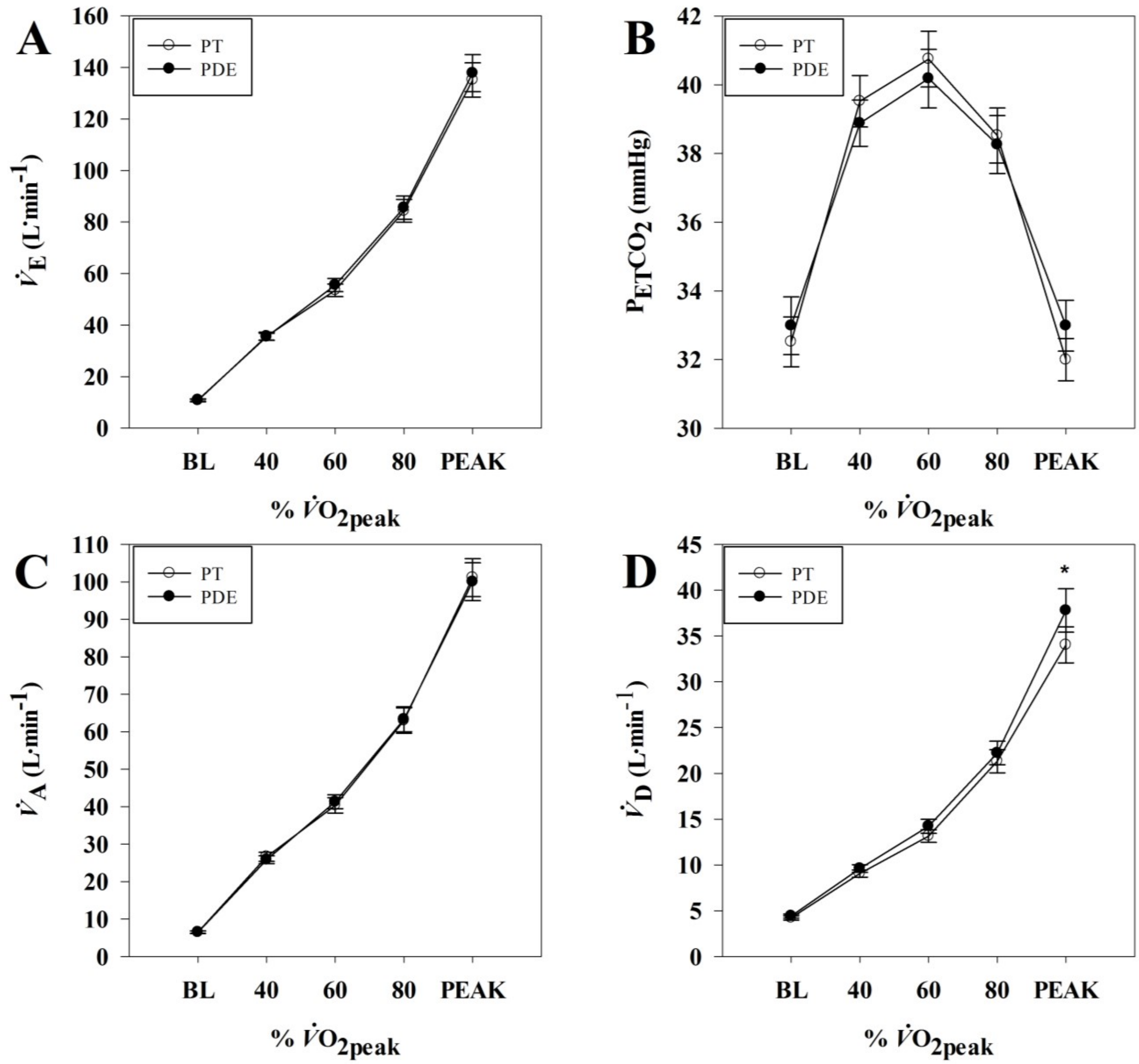

Figure 3-1. Mean (±SE) minute ventilation ($\dot{V}_E$, L·min^{-1}) (A), partial pressure of end-tidal carbon dioxide ($P_{ET}CO_2$, mmHg) (B), alveolar ventilation ($\dot{V}_A$, L·min^{-1}) (C) and deadspace ventilation ($\dot{V}_D$, L·min^{-1}) (D) at selected exercise intensities (%$\dot{V}O_{2peak}$) during treadmill exercise tests in physical training (PT) and police duty ensemble (PDE) conditions. (n=25); BL, baseline; * indicates $p<0.05$ vs. PT condition.

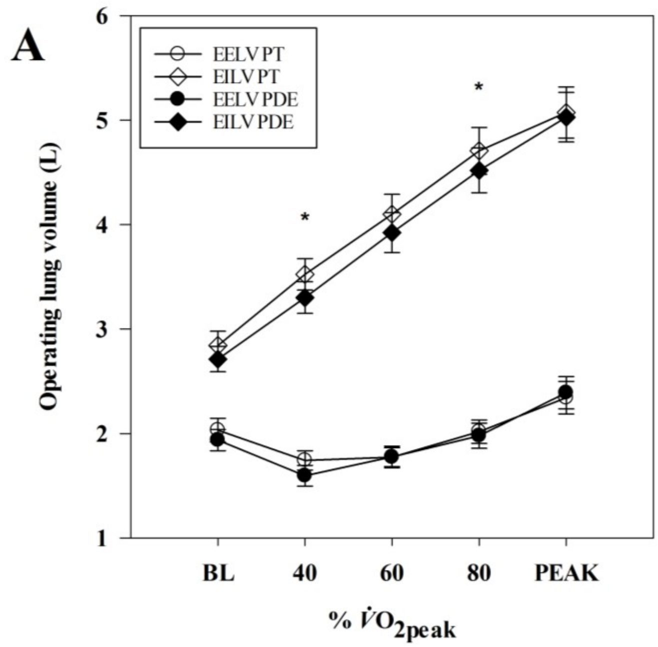

Figure 3-2. Mean (±SE) resting and operating lung volume in PT (open symbols) and PDE (closed symbols) conditions, shown as absolute volume (L) (A) and a percentage of the forced vital capacity (B) at selected %$\dot{V}O_{2peak}$ during the graded exercise tests in two conditions, PT and PDE. (n=25); BL, baseline; PT, physical training; PDE, police duty ensemble; EELV, end-expiratory lung volume; EILV, end-inspiratory lung volume; *indicates $p<0.05$ vs. PT condition.

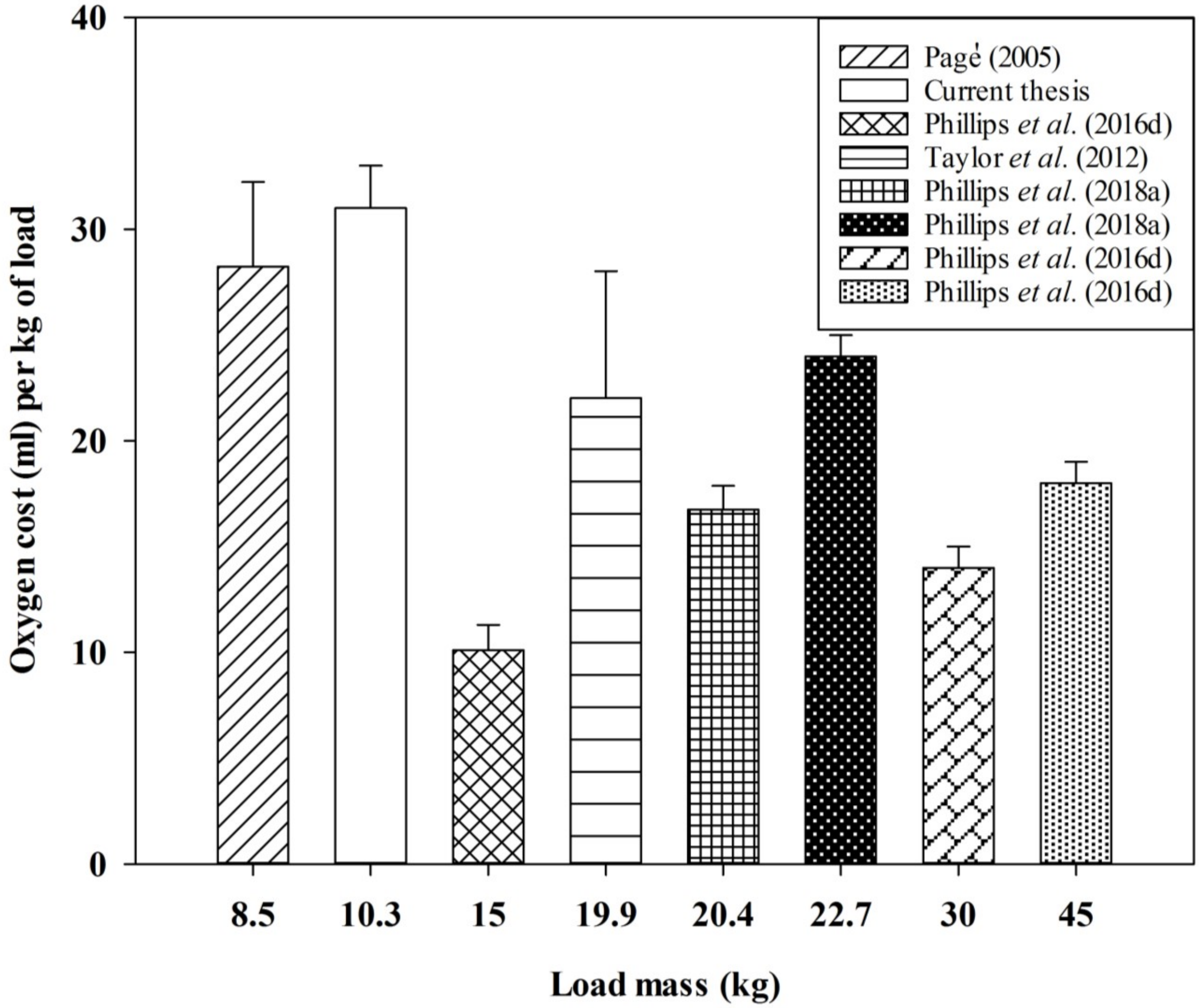

Figure 3-3. Mean (±SE) oxygen cost (ml) per kg of load mass during submaximal treadmill walking from selected experiments. From left to right, the experimental conditions were: police duty ensemble, walking at 93.9 m·min^{-1}, 3% grade (Pagé 2005); police duty ensemble, walking at 93.9 m·min^{-1}, 4% grade (current experiment); backpack, walking at 80.4 m·min^{-1}, 4% grade (Phillips *et al.* 2016d); fire protective ensemble, walking at 80 m·min^{-1}, 0% grade (Taylor *et al.* 2012); backpack, walking at 93.9 m·min^{-1}, 1.5% grade (Phillips *et al.* 2018a); backpack, walking at 93.9 m·min^{-1}, 1.5% grade with protective clothing and occupational footwear (Phillips *et al.* 2018a); and, backpacks, walking at 80.4 m·min^{-1}, 4% grade (Phillips *et al.* 2016d).

Chapter 4 – General Discussion and Future Directions

4.1 General Discussion

In previous chapters, the background and rationale for this study were discussed in depth. The results of this investigation and a discussion of the main findings were presented in the third chapter. This chapter seeks to: fill the gaps between the main findings of this investigation and the over-arching field of occupational physiology; to seat this investigation in the literature; and, to address the interpretation of this investigation in the field and the limitations of its interpretation.

4.1.1 Cardiopulmonary Implications

It was originally hypothesized that police duty ensemble would impact the cardiopulmonary system during peak exercise, however, our results suggest otherwise. Pagé (2005) reported in her unpublished MSc thesis, that that at peak exercise, tidal volume was reduced, breathing frequency was increased, and minute ventilation was unchanged by a similar duty ensemble. In the current experiment, there were no statistically significant changes in any of the peak variables. The reasons for this are likely two-fold. First, the previous work was conducted with police officers wearing their own equipment. This equipment was custom fit for them and they would have adjusted it to the fit that they personally deemed comfortable. Personal comfort and familiarity with equipment does not guarantee adherence to correct fitting as dictated by a manufacturer. The fitting process was less standardized and retrospectively we are not able to confirm if manufacturer specifications or guidelines similar to those outlined by Sabol *et al.* (2014) were followed, as a detailed fitting protocol is not specified in Pagé (2005). This may have led to over or under adjustment of the equipment and may have added variability to the results.

Second, the previous research was completed with a sample of female subjects. It is well known that there are anatomical differences between males and females in the pulmonary system.

For instance, females have smaller lung volumes, lower maximal expiratory flow rates, smaller diffusion surfaces, and smaller airways (Sheel *et al.* 2004; LoMauro and Aliverti 2018). Any sex-based differences in physiological responses during treadmill exercise due to the interaction of sex, police duty ensemble, exercise intensity, and anatomical differences may have been hidden in our sample that contained both male and female participants. Finally, readers may be tempted to speculate that certain data suggests a trend (despite non-significance), specifically: reduced tidal volume, increased breathing frequency, and increased minute ventilation at peak exercise. Despite this speculative trend, alveolar ventilation was maintained throughout all selected exercise intensities and at peak exercise (Figure 3-1). Prospective effect and sample size calculations have been included in Appendix D to highlight that the possibility of attaining significance in our investigation was extremely unlikely. To summarize, there is no compelling evidence that the duty ensemble, and specifically the body armour, constrained exercise ventilation during our investigation.

4.1.2 Work Performance

In the realm of work physiology, there are many work simulations for physically demanding occupations. Many established work simulations are also used as tests of physical aptitude for work. The A-PREP pursuit/restraint circuit is a good example of this and it is recognized as both a model of police work and a physical readiness for work evaluation (Gledhill and Jamnik 2007; Gumieniak *et al.* 2013). While the A-PREP has a cut-score, it is important to understand that there is no objectively measured data available in the literature that compares performance on a task-based model of police work to actual performance on the job. Therefore, this study and other studies examining the impact of occupational load carriage on mobility tasks provide the basis for understanding how occupational load carriage impacts mobility and task completion. However, the results are not necessarily associated to or predictive of work performance in real world policing.

4.1.3 Sub-Analysis and Current Topics in Occupational Physiology

A number of sub-analyses were conducted in an attempt to glean insight into some current topics in occupational physiology such as the influence of body mass on performance, sex differences, the effect of learning, and task specific interval performance during the work simulation. These sub-analyses appear in Appendix C and are referenced throughout Chapter 4.

Body mass has been shown to have a mild influence on performance during tasks involving thoracic load carriage (Phillips *et al.* 2016b, Phillips *et al.* 2017). While important and potentially relevant, the investigations looking into this phenomenon have involved heavier thoracic load carriage (*e.g.* ~25 kg) in backpacks or fire-protective ensemble. To determine the influence of body mass on performance with police duty ensemble, both treadmill and circuit performance were compared with respect to body mass (Figures C-2, C-5, and C-6, respectively). Regression analysis reveals r^2 values of 0.03 and 0.22, respectively, for treadmill and circuit performance time (s) when compared to body mass. This would suggest that body mass has little influence on performance while wearing duty ensemble. When comparing performance time (s) in duty ensemble to $\dot{V}O_{2peak}$, regression analysis reveals r^2 values of 0.50 and 0.65 on the treadmill and circuit, respectively. This would suggest cardiorespiratory fitness is a more powerful predictor of performance than body mass.

When examining sex differences, the typical method used in the literature is to match males and females on one, or a few selected physical characteristics. These commonly include height, body mass, or cardiorespiratory fitness. To conduct this matching in our sample would be underpowered and irresponsible as it was not a primary outcome for the investigation. Further, there are other studies that have investigated sex differences using matched pairs and other methodology, and they provide the basis for our contemporary understanding of sex differences with occupational load carriage (Krupenevich *et al.* 2015; Phillips *et al.* 2016c; Phillips *et al.* 2018a,b; Scarlett *et al.* 2018). To attempt to answer questions related to sex, performance on both the treadmill and work simulation have been broken down by sex and compared using one way ANOVA. On the treadmill in duty ensemble, males had a performance time (s) reduction of 14 ± 1% and females 15 ± 1%. On the circuit, the relative performance time change was 9 ± 1% for males and 11 ± 3% for females when comparing PT to PDE (Figures C7-C12). In both cases, these differences were not significant ($p>0.05$). This would suggest that performance was impacted in a similar manner for both males and females and this is in line with other reports (Phillips *et al.* 2016c; Phillips *et al.* 2018a,b; Scarlett *et al.* 2018). Note this sex comparison data is speculative; it was not part of the study design or a primary outcome.

With any work simulation or task-replication for a physically demanding occupation, a learning effect is likely to influence performance. This means that a person will not necessarily perform their best on the first, second, or even third time that they conduct a testing battery. As such, proper practice is essential in order to attempt to remove any variability associated with learning and attempt to get as close to the true score as possible, notwithstanding that human performance is variable from day to day within a small margin (Katch *et al.* 1982; Bagger *et al.* 2003; Teo *et al.* 2011). In accordance with the findings presented by Boyd *et al.* (2015), our subjects were given ample coaching and practice in order to ensure that their pacing strategies were as well developed as possible. By the time experimental data were collected, our participants had conducted the work simulation twice in each experimental condition for a total of six repetitions. This is greater than the 3-4 times required to see a flattening of performance change in

Boyd *et al.* (2015). Our work simulation sessions (9 total) were conducted in a balanced, randomized fashion. Performance times were then analyzed with a two-way, repeated measures ANOVA. This revealed that, independent of condition, participants improved their performance between testing days, but there was no difference in performance throughout any one individual testing day (3 work simulations per day, conducted over 3 days). This analysis is presented in Figure C-16, and confirmed that the effect of learning had been minimized. Additionally, pilot work demonstrated that more testing sessions did not improve performance any further.

The work simulation can be broken down into three categories of tasks: running/agility, musculoskeletal strength, and anaerobic power/endurance. Respectively, these align with the pursuit portion (running, stair climbing, and vaulting the wall), the restraint portion (the body control simulator and arm restraint simulator), and the victim drag or casualty evacuation. A small observational sub-analysis with four subjects was conducted to determine the change in task-specific interval performance on this work simulation (see Table C-2). This sub-analysis revealed that the most impactful performance changes occurred on the pursuit portion of the circuit (running) and the victim drag. This would be congruent with the literature that relates to the impact of load carriage and occupational equipment on mobility (Treloar and Billing 2011; Carlton *et al.* 2013; Dempsey *et al.* 2013; Lewinski *et al.* 2015; Taylor *et al.* 2016a; Joseph *et al.* 2018). As such, the tasks with a low mobility requirement have fairly similar interval times.

To summarize: body mass had a small impact on performance, there were no apparent of sex differences in treadmill or work simulation performance, the learning effect was accounted for, and duty ensemble appears to influence tasks involving mobility more than tasks with a heavy musculoskeletal strength component.

4.1.4 Practitioner Summary

Practitioners must, at all times, consider that the basic minimum load a general duty police officer must carry is prescribed and is non-negotiable. It is the job of the practitioner to understand how the duty ensemble impacts physiological responses, and how this may impact job performance (*e.g.* reduced mobility, reduced running speed, less physiological reserve to devote to locomotion or fighting). The practitioner must effectively communicate these realities to the officers that they serve. Duty ensemble should be included in any physical training that includes a work simulation component, an assessment of physical readiness for work, and any return to work program or assessment. Where the actual duty ensemble is not available, the duty ensemble must be replicated as faithfully as possible. The ensemble must not be modified for an individual unless authorized by the employing organization. Finally, it is important to note that the burden of the duty ensemble may be higher with the addition of clothing for inclement weather or heavier footwear.

4.2 Future Directions

4.2.1 Prolonged Exercise

While no cardiopulmonary implications were observed in this study at peak exercise, it is important to consider that we only examined one model of exercise. The relevance of this model is strong when it comes to policing, but our findings during steady-state exercise and peak exercise intensity only represent some policing tasks of similar duration and intensity. There is a large gap in the literature regarding moderate-high intensity exercise for a sustained duration of time with police duty ensemble. This has occupational relevance for patrol officers who may be involved in a long duration foot chase or for specialty sub-occupations of law enforcement like canine or tactical units.

With thoracic load carriage, the impact of loads up to 25 kg on the normal ventilatory response to exercise was not apparent during moderate intensity exercise until observed prolonged model, greater than 20 minutes (Phillips *et al.* 2016a). By extension, it could be assumed that any similar alteration to the normal ventilatory response may go unobserved until a prolonged moderate intensity exercise model is used with the police duty ensemble.

These questions may not be appear to be immediately relevant to patrol officers, but may become increasingly important in the future with the increased use and specialization of canine and tactical units in police forces across the country. Additionally, the idea of prolonged exercise may be more applicable to police forces responsible for vast geographical areas spanning rural and remote locations, like the RCMP or Ontario Provincial Police (OPP).

4.2.2 Physical Demands Characterization

Future research in this area could seek to catalogue real time tasks that police encounter in order to better understand the job demands. A good example of this would be using body camera footage combined with new technological advancements like heart rate monitoring and GPS tracking. These data may develop more complete task analysis packages in law enforcement and may help when developing tests of physical employment standards, when setting physical employment standards, or when dealing with physical training for work. Many task analysis projects in law enforcement are aged and may not represent the current policing climate. Further, advancements in task analysis and activity cataloguing would be a catalyst to synthesize work being conducted in the physical employment standards realm with work in the psychological and psychophysical realms. This may help bolster the physical and psychological readiness and resiliency training initiatives that many emergency response organizations are championing.

4.2.3 Occupational Safety Considerations: From Testing to Practice

As with other physically demanding occupations, law enforcement officers are expected to be physically fit for duty. The current model of testing in law enforcement, however, has two primary flaws. The first is that general duty patrol officers are seldom required to undertake testing for fitness on an annual basis (Anderson *et al.* 2001). Officers have to pass a physical readiness evaluation upon recruitment and selection, but are rarely assessed on physical fitness again where the test results could have implications in their career progress (Anderson *et al.* 2001). For example, the Edmonton Police Service conducts health screening and annual physical fitness evaluations, but these evaluations are not based in physical employment standards and officers cannot have their employment jeopardized by the results of these assessments. The importance of health and fitness in the law enforcement community, both for the sworn members and the communities they protect, is something that must be considered in the larger context of this research.

The second concern with physical readiness evaluations in law enforcement is the testing models that they follow and the potential concerns that arise from those tests. In the work simulation we examined, participants complete the circuit while wearing a weight belt. Our results show that any impact to performance induced by this belt is not detectable, and the performance most closely matches completing the circuit in physical training clothing. In other words, the weight belt fails to alter performance compared to the unloaded condition and further fails to produce the same impact on completion time as the duty ensemble. Thus, the testing condition of the weight belt is wholly ineffective at simulating the occupational equipment that officers must wear in the performance of their duties. If these findings are considered in parallel with cut-scores on physical readiness for work evaluations, the importance of the duty ensemble in the creation of the cut-score is apparent. In some way, the impact of the duty ensemble must be considered during cut-score development if a cut-score is to accurately reflect the actual fitness required to work in the duty ensemble.

Chapter 4 – References

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Chapter 5 – Conclusion

During steady-state exercise with police duty ensemble, both metabolic cost and physiological strain were increased. These increases are greater than what may be expected by load mass alone, and are likely due to a combination of load location, interaction of clothing layers, and occupational footwear.

During graded treadmill exercise, there were no obvious changes in the cardiopulmonary response to exercise, as indicated by the variables measured. The cardiopulmonary system appears to have sufficient reserve to compensate for the duty ensemble. At selected intensities relative to individual $\dot{V}O_{2peak}$, there are no differences in either $\dot{V}_E$, $P_{ET}CO_2$, or $\dot{V}_A$, verifying that any changes to the normal ventilatory response due to the duty ensemble are compensated for by the cardiopulmonary system in this model of exercise. Despite no implications for the cardiopulmonary system, performance implications were observed. Treadmill time and peak treadmill grade were reduced with the duty ensemble. Power output may correspond to peak running speed or tolerance time in an occupational setting.

During the work simulation, performance was reduced when wearing the duty ensemble while physiological strain was either equivalent or increased. This shows that despite consistent effort from the participants, they were unable to replicate unloaded performance when wearing duty ensemble. Furthermore, the weighted belt testing condition that is meant to simulate the duty ensemble was shown to be ineffective, as participant's test scores were the same between the WB and PT conditions. Therefore, the weight-belt did not accomplish the purpose intended.

Overall, despite its low mass, duty ensemble has a significant impact on physiological responses during steady-state walking, during graded exercise to exhaustion, and also during simulated work performance. It is important that the duty ensemble be included in physical readiness testing for police work and physical training for police work (including return to work protocols post-injury). In order to faithfully reproduce the full impact of the duty ensemble in testing and training situations, scientists and practitioners must understand the implications of load mass and distribution on mobility and the physiological response to exercise.

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Appendix A – Experimental Apparatus

Plate A-1. The two-way, non-rebreathing valve (Hans Rudolph, Kansas City, MO, USA) with: inspiratory pneumotach (left), ports for $ETCO_2$ and mouth pressure (top), and expired gas collection (right).

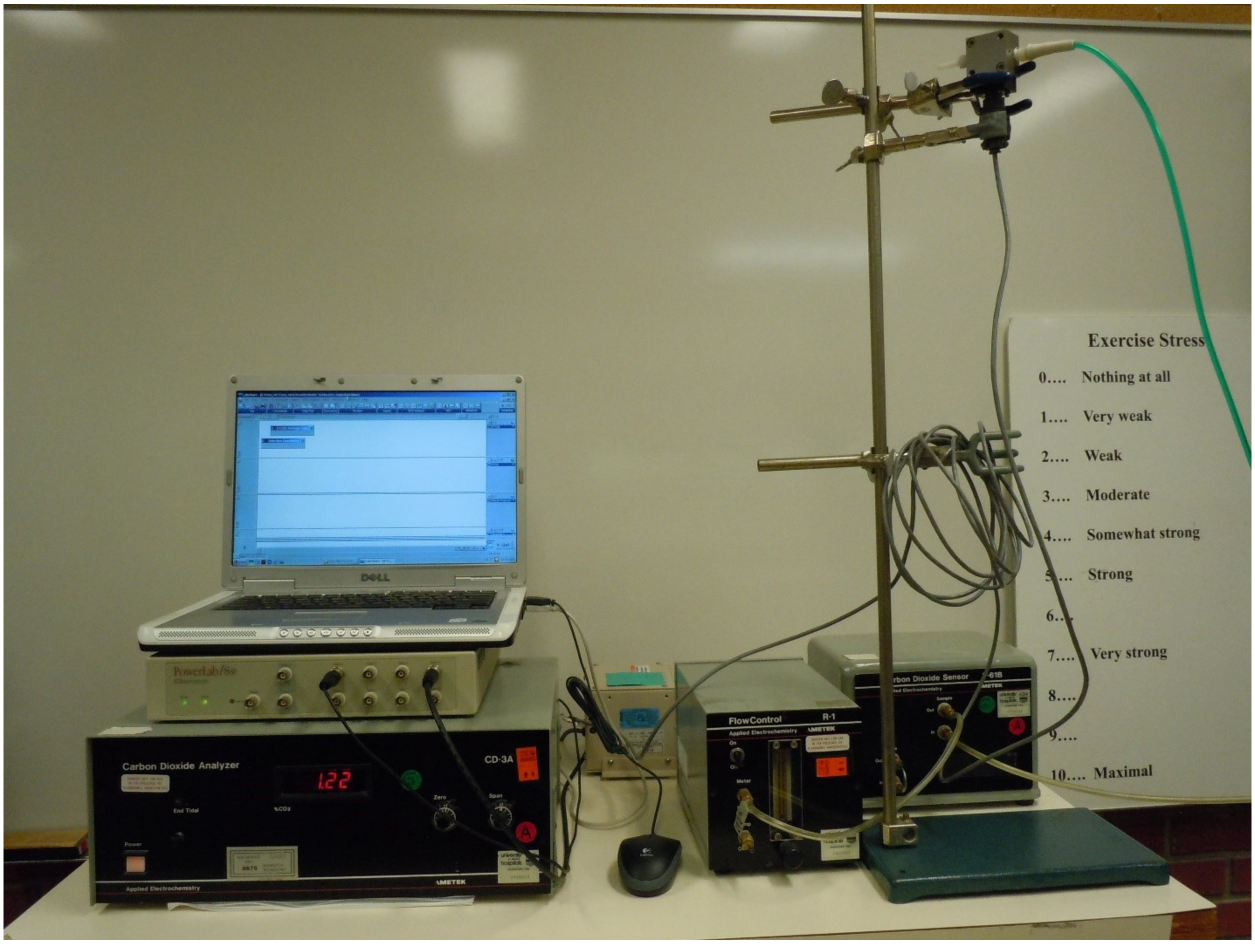


Plate A-2. Carbon dioxide analyzer (R-1 pump, P-61B sensor, CD-3A CO_2 analyzer, AEI Technologies, Naperville, IL, USA) and data acquisition system (Powerlab 8/35, ADInstruments, NSW, Australia). Differential pressure transducer (DP15, Validyne, Northridge, CA) with surgical tubing. The pressure transducer signal was amplified using a demodulator (CD280, Validyne, Northridge, CA) and recorded with the same data acquisition system. Note the modified Borg scale (right of frame) for collecting perceptual response data; this sign-board was located directly in front of the treadmill.

Plate A-3. Police duty ensemble. From top left of the frame to bottom right of the frame: Taser (X2, Axon, Scottsdale, AZ, USA), spare ammunition magazines for side-arm, retractable baton, radio with microphone, flashlight, handcuffs (x2), replica of the Edmonton Police Service standard issue sidearm (Glock 22, Glock Inc., Smyrna, GA, USA), OC (oleoresin capsicum) spray, concealable body armour (Revolution, Armor Express, Central Lake, MI, USA), boots (Original SWAT Classic 9", Georgetown, ON, Canada), patrol uniform (Prestige/Distinction Short Sleeve Shirts/Pants, Elbeco, Reading, PA, USA), and insert-able trauma plates for the concealable body armour (front and back, respectively). The duty belt shown was used by all subjects (in their respective sizes) (Deluxe Duty Belt [inner/outer], Uncle Mike's Tactical, Overland Park, KS, USA).

Plate A-4. Concealable body armour (Revolution, Armor Express, Central Lake, MI, USA) from front and back, respectively, with trauma plates installed.

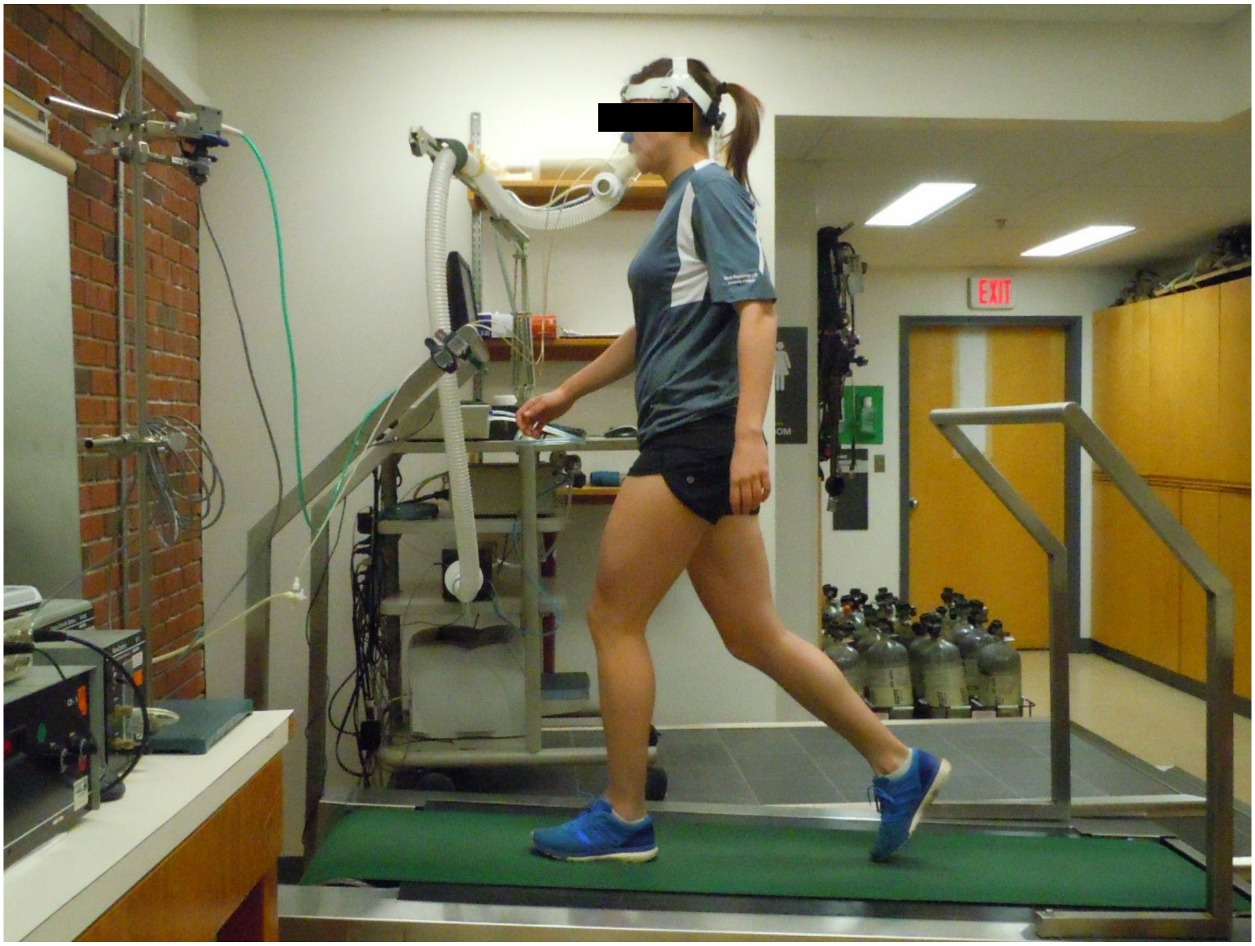


Plate A-5. The complete experimental apparatus with a subject walking on the treadmill in the PT (physical training) condition.

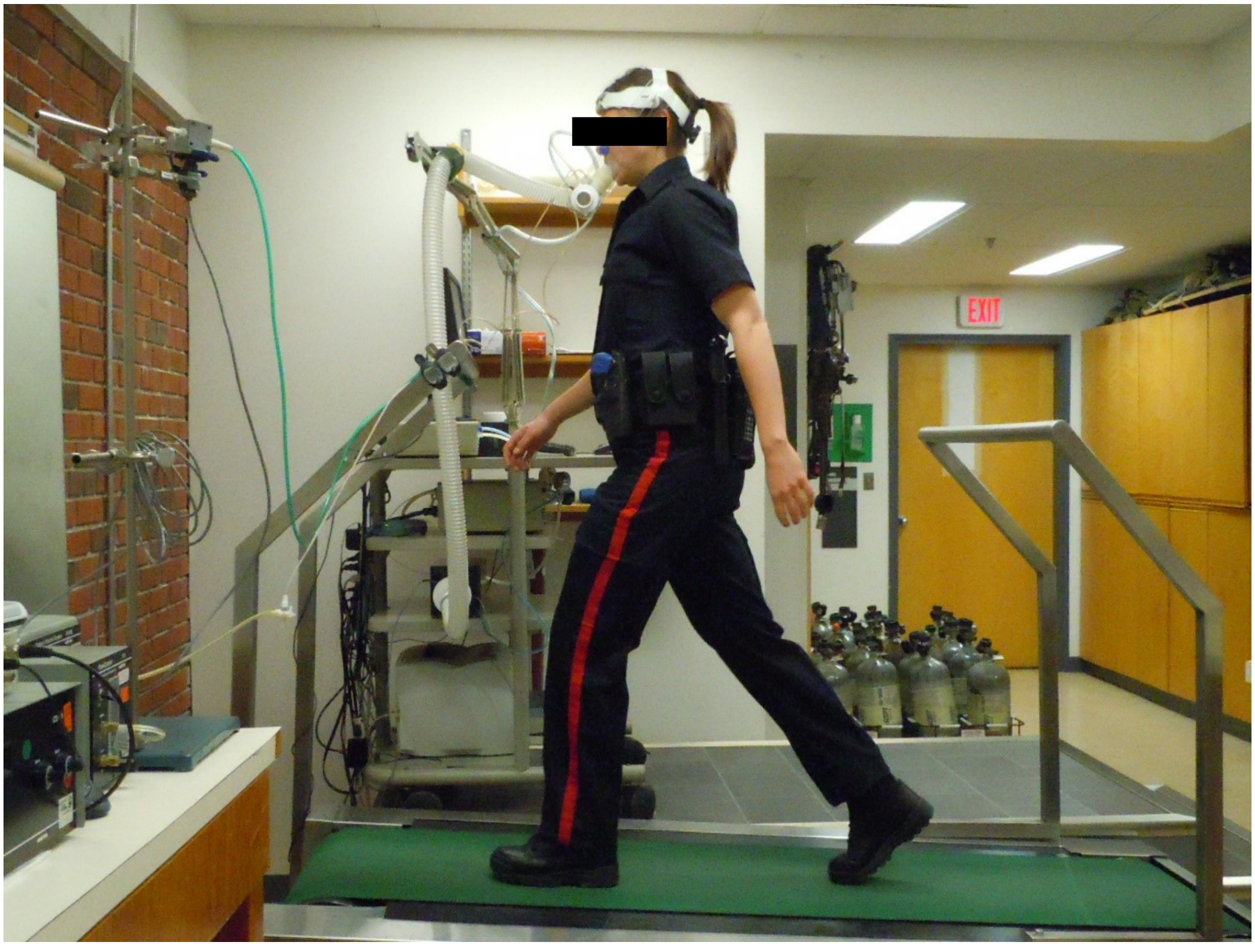


Plate A-6. The complete experimental apparatus with a subject walking on the treadmill in the PDE (police duty ensemble) condition.

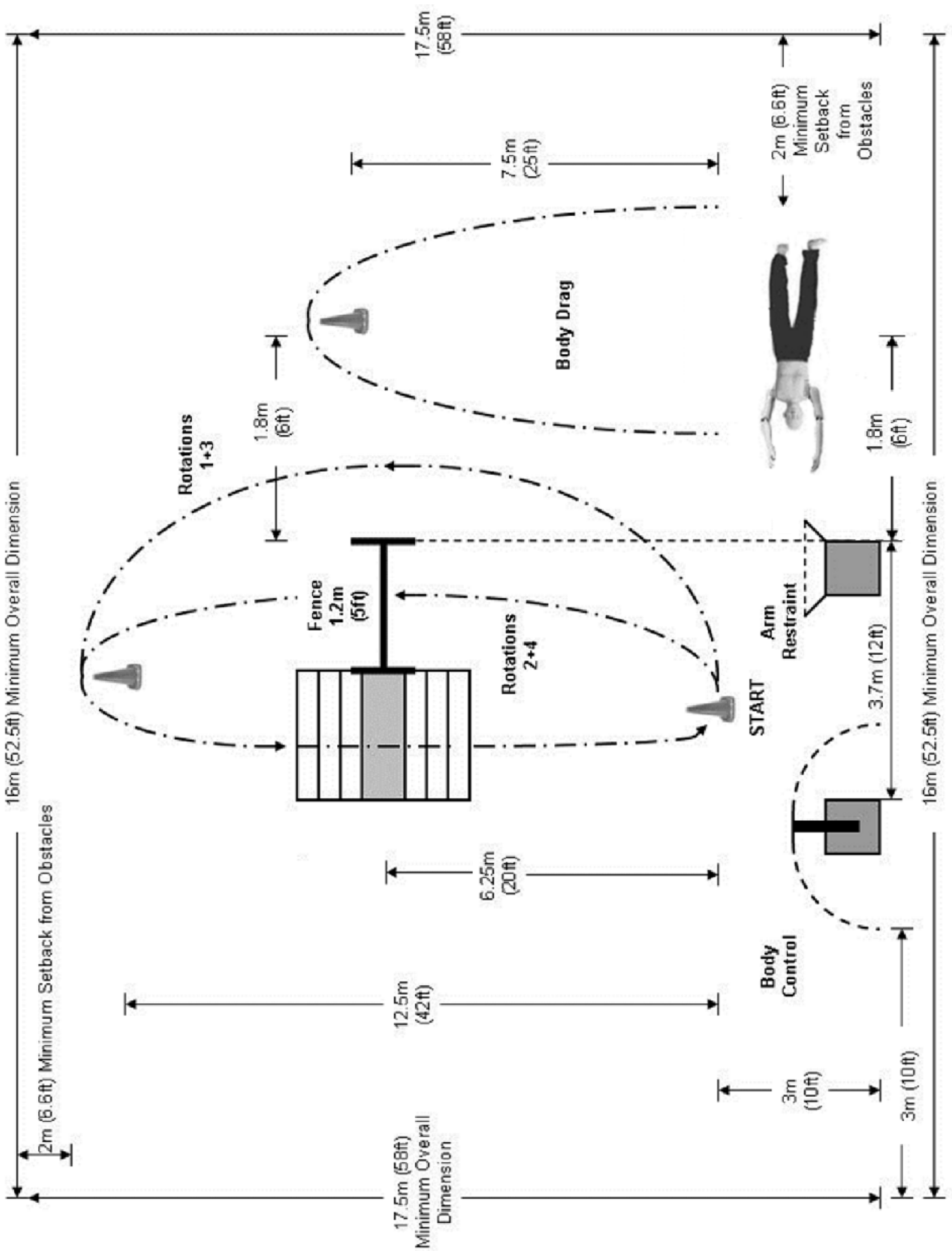


Plate A-7. Schematic of the work simulation circuit (Alberta Physical Readiness Evaluation for Police) (Edmonton Police Service, 2014).

Plate A-8. Subject in the starting position on the work simulation (Alberta Physical Readiness Evaluation for Police circuit) in the three conditions. From left to right, PT (physical training), WB (weight belt), and PDE (police duty ensemble).

CHAPTER 5.

Measurement, Fit and Coverage

Importance of Proper Measurement and Fit

The goal for any ballistic-resistant armor is to maximize ballistic protection while minimizing its impact on an officer's ability to perform normal duties. As with other protective equipment, body armor can afford an officer only a certain level of protection before it impairs mobility and physical performance. The selection process should try to achieve a balance that will maximize the armor's ballistic protection and coverage while minimizing its impact on duty performance. Proper measurement and fit are also keys to ensuring a reasonable degree of comfort.

Proper Fit and Coverage

Ballistic-resistant armors (when worn) are key life-saving equipment. With proper fit, an armor should ensure maximum coverage without hindering an officer's mobility or ability to perform required job functions. Although comfort is a subjective term, increased comfort through proper fit is an important objective. NIJ-funded research suggests that armors that have been fitted by the manufacturer, working with agency representatives, are the ones that officers find most comfortable.

Measurement Guidelines

Having body armor that fits well and is comfortable begins with obtaining appropriate and accurate measurements. Some, but not all, armor suppliers have trained representatives who conduct proper measurement and fitting. Officers can benefit from understanding measurement and fitting techniques as well as the area of coverage the body armor should provide.

At NIJ's request, an ASTM International committee that included law enforcement and correctional officers, developed and published ASTM E2902-12, *Standard Practice for Measurement of Body Armor Wearers*. The purpose of this document is to increase consistency in how measurements are made by specifying the process for measuring officers being fitted for new armor.

NIJ has a contract with ASTM to provide access to LE-specific standards at no cost to any verified public safety agency. For further details about access to this service, please send an email to asknlectc@justnet.org from a valid email address demonstrating that you are a current/active member of a federal, state or local law enforcement, corrections or forensics agency. Personal email addresses (e.g., Gmail, Yahoo, etc.) are not allowed. Once your agency email address has been confirmed, you will be given login credentials that will give you access to the ASTM site. This agreement will be good for one year, and can be renewed annually using your official agency email address.

Fit and Coverage

Soft armor (daily wear). The following guidelines have been developed to help agencies determine if a soft armor fits appropriately and provides appropriate coverage. These guidelines apply both to armors worn over and under the duty uniform (additional guidance on the fit of tactical armor is addressed later in this chapter) For a pictorial representation of proper fit, see Exhibits 14a and 14b; for a graphic breakdown, see Exhibit 15.

- Prior to donning the armor, open the carrier and examine the label on each ballistic panel. Verify the label faces the correct direction. The label may say “Wear face,” “Strike face,” “This side toward body” or something similar. Many body armors are designed to work in one direction only; inserting the panels in the incorrect direction can result in the armor's failing to perform as intended. The materials used may differ from strike face to body side and have different effects on the bullet or knife and may not work if the armor is worn backwards.

- Place the panels into the carrier and don the armor such that the front panel is over the front of the body and the back panel is over the back. The front panel can generally be identified by its having a scoop at the neckline.

- After the armor is donned, do not over tighten the straps. It is human nature to cinch the straps down as tightly as possible, and this is a common mistake. The armor should fit snugly, but not so tightly that it may affect breathing (including deep breathing, such as may occur during a foot chase). The armor should slide slightly on the body as the torso is rotated back and forth. If the armor moves with the body, it is probably too tight.

- To ensure appropriate side coverage for both over-the-uniform and under-the-uniform armors, the sides of the torso armor should always overlap by approximately two inches front to back (i.e., the front panel should lie on top of the back panel). This may prevent a bullet from a frontal shot from entering between the panels, traveling inside the back panel and entering your body. This provides additional protection against near-edge shots and also allows for expansion if an officer gains weight over time without creating a dangerous gap.

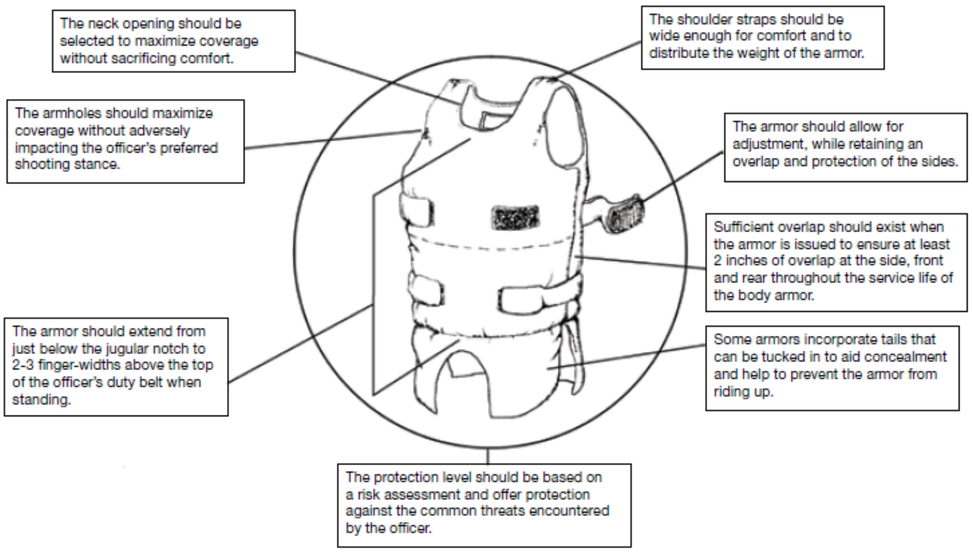
- Ballistic coverage under the arms should be as high as possible without compromising the ability to obtain a shooting position. Over-the-uniform armor may afford slightly greater protection in this area.

- The length of the panels relative to the body is very important. For concealable (under-the-uniform) soft armor, the front panel should extend from just below the jugular notch to two to three finger-widths above the top of the belt when standing. For over-the-uniform armor, the armor can be slightly longer without impeding movement or comfort. This gap may vary slightly from person to person but is normal and necessary, and prevents the panel from being pushed up into the throat when the officer is seated. Proper fit can be confirmed by sitting down with the armor on. When seated, the front panel should ride just on top of the belt but should not shift up into the throat. If it does, contact the supplier for a fit adjustment. The rear panel should extend from approximately two inches below the collar to approximately one inch above the belt.

EXHIBIT 14A: SOFT BODY ARMOR FIT AT NECK

EXHIBIT 14B: SOFT BODY ARMOR FIT AT DUTY BELT

EXHIBIT 15: SOFT BODY ARMOR FIT



At the time of purchase, check to confirm that the armor panel (not just the carrier) has at least the minimum 2-inch overlap as recommended.

Additional Fit and Coverage Guidance for Tactical Armors. Because tactical armors are worn externally (outside/over the uniform), fit is slightly more forgiving and coverage should be greater than that of a soft armor worn for general duty. This, along with the fact that tactical armors are not typically worn for extended duty periods, but rather in response to heightened threats, allows for slightly more coverage than over-/under-the-uniform duty armor.

Specifically, tactical body armor is longer and should end roughly at the top of the duty belt when standing. See Exhibit 16. It should not, however, overly restrict access to items on the duty belt and should never prevent drawing of a weapon. Tactical armors may have additional integral coverage extending over the shoulders. Although this provides additional coverage and ballistic protection, officers should trial the armor prior to use to ensure that it does not inhibit necessary movements or range of motion, such as shouldering a weapon or restraining a suspect. Tactical armors may also have available accessory ballistic panels (i.e., extremity protection). Such accessories should be tried on immediately on receipt to ensure compatibility.

EXHIBIT 16: TACTICAL ARMOR FIT AT DUTY BELT

Hard armor plates are available in multiple sizes. The most common sizes are 10-inch x 12-inch and 8-inch x 10-inch. In addition to various available sizes, hard armor is also available in various curvatures and various shapes. The front and rear plates should be positioned to provide additional protection to the aortic region. However, the coverage will not be as extensive as that of the underlying soft armor panel. Some hard armor plates are curved in only one direction while others are curved in multiple directions, and the curvature may directly relate to the plate's ballistic performance. Some plates have rectangular perimeters whereas others are angled at the shoulders to facilitate arm movement (e.g., to allow taking a shooting stance). These shapes can vary from model to model. The purchasing agency or officer should take mobility and coverage into consideration when evaluating hard armor to purchase.

Plate A-9. Measurement, fit, and coverage guidelines for body armour from the National Institute of Justice (Sabol *et al.* 2014).

Appendix A - References

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Sabol, W.J., Tillery, C., Stoe, D., & O'Shea, M. 2014. Selection & application guide 0101.06 to ballistic-resistant body armor. U.S. Department of Justice - National Institute of Justice, Washington, D.C.

Appendix B – Data Sheets

PARTICIPANT INFORMATION

The Impact of Police Equipment on the Cardiopulmonary Responses to Treadmill Exercise and Simulated Police Work

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Thank you for your interest in this study. Please read over the following information that explains what the study is about and what is involved in being a participant. You are welcome to ask questions about the study and at each stage of the project, we will review all the relevant procedures with you in detail.

Background

A common element across almost all emergency response occupations is load carriage. Law enforcement officers carry loads that include uniforms, duty belts, weapons, body armour, communications systems and other equipment.

Load carriage impacts human exercise performance in a number of ways; primarily, by increasing physiological strain (minute ventilation, heart rate, perception of exertion), and by decreasing performance (task completion time or quantity of work completed).

It is important for employers to know the physiological impact of the equipment used by employees and this is related to work standards, health and safety, and the assessment of fitness for duty.

Study Protocol

Overview

The study consists of 6 parts that will be scheduled on separate days over a period of approximately two weeks. The duration of each part will vary between 1 and 2.5 hours, and the ***total time commitment will be approximately 18 hours***.

Each part is designated as a “Study Day” and these are numbered from 1 to 6.

Normally, at least one “day off” will be scheduled in between Study Days so that you can recover and come to the next study day refreshed and ready to exercise. We will ask you to be consistent with physical activity, sleep and nutrition throughout the whole study period. We will discuss how to best manage physical activity outside the study, sleep and nutrition with you at enrollment when your study appointments are being scheduled.

Normally, we will try to schedule all your tests at approximately the same time of day.

Study Day 1 – Screening and Enrollment
Before we enroll you in the study, we will ask you to complete a short health questionnaire called the PAR-Q+. The purpose of the PAR-Q+ is to identify any problems associated with exercise.

After you complete the screening procedures and are enrolled in the study, we will fit you with clothing, boots and equipment such as the duty belt and body armour. You will have an opportunity to exercise briefly while wearing this ensemble to make sure that everything fits comfortably. You will also be introduced to the measurements that we will take during the treadmill exercise portion of the study.

This session will take about two hours.

Study Days 2 & 3 – Graded Exercise Tests (GXT)
On separate days, you will complete two graded exercise tests (GXT) to exhaustion on a treadmill. The two tests will be in either regular exercise clothing or police duty ensemble. The order of the two tests will be random (like flipping a coin). These tests will be incremental protocols to exhaustion. During the test you will walk briskly (3.5 mph or 94 m.min-1) and the treadmill grade will increase by 2% every two minutes until 4% grade is reached. The 4% grade workload will remain unchanged for 6 minutes. Following this extended stage, the test resumes 2% increases in grade every two minutes, until you cannot continue. This extended workload at 4% grade allows us to examine walking economy at a sub-maximal exercise intensity.

During these exercise tests, you will breathe through a special mouthpiece so that we can monitor your breathing and measure how much oxygen you are using. The rate of oxygen use is low at rest and increases as you work harder. The highest rate of oxygen consumption is called VO2peak, and we usually find this value right near the point of exhaustion. VO2peak is generally considered the best measure of aerobic fitness.

Before the test starts you will warm-up on the treadmill and after the test is over, you will cool-down with easy walking. Also, before and after the tests you will complete a series of tests to

evaluate your lung function (spirometry). We will always keep you in the lab for a while after the test to monitor your recovery.
Including the time necessary for preparation, pre-exercise spirometry, warm-up, the test, cool-down, and post-exercise spirometry, we estimate that the time required for each test is approximately 60 to 90 minutes.

A-PREP Circuit Protocol
The Alberta Physical Abilities Readiness Evaluation for Police Officers (A-PREP) Circuit portion of this study includes a pursuit/restraint circuit that simulates police job-related tasks. This portion of the study will utilize the same control and experimental conditions as the graded exercise test portion and an additional experimental condition where you will wear PT gear with a weighted belt.

Study Days 4 & 5 – A-PREP Circuit Practice
We will show you the A-PREP police test circuit and familiarize you to the order of the job related tasks. You will have an opportunity to walk through the circuit, try everything, ask questions, and receive technique coaching from the researchers in a relaxed environment. This walk through is not meant to be fatiguing.

You will practice the A-PREP circuit in order to minimize any learning effect that may be present. Each practice session will consist of completing the circuit in all three conditions, in random order, with a standardized rest and recovery in between. Further, the practice sessions will allow you to become accustomed to having a researcher track your heart rate and record your perceived breathing stress and level of exertion while you complete the circuit.

These practice sessions will approximately two hours.

Days 4 & 5 will be separated by at least one day of recovery.

Study Day 6 – A-PREP Experimental Trials
On day 6 you will complete the A-PREP circuit in all three experimental conditions, in random order (like flipping a coin). Experimental trials will be separated by the same standardized rest and recovery as in the A-PREP Circuit Practice Days. Performance time and markers of physiological strain (heart rate and perception of exertion) will be measured in each condition in order to determine the effect of the police duty equipment on performance.

Other Measurements
During the exercise tests (treadmill and police tests) we will ask you to rate your overall level of effort (“how would you rate your exercise stress?”), your breathing stress (“how would you rate your breathing stress?”). We use simple charts with rating scales that show the range from “minimal” to “maximal”. When we ask for your rating, you just need to indicate your place on the rating scale with a simple hand signal.

Benefits
There may not be any direct benefit to you from participating in this experiment. You will learn about your fitness level from the results of the tests. Most people who are physically active and are interested in exercise find this information valuable. This study will provide the researchers with information about how wearing police duty equipment affects breathing during exercise and how the different clothing ensembles affect work capacity.

Risks
All of the procedures used in this study are common in exercise physiology experiments. The risks to healthy individuals are minimal. However, before you can enroll in the study, we will confirm that you have no present or previous medical history that indicates that is it unsafe for you to participate.

The treadmill test requires maximal effort in order to keep exercising until exhaustion. There may be some health risk with this type of exercise. During and following test, it is possible that you may experience symptoms such as abnormal blood pressure, fainting, lightheadedness, muscle cramps or strain, nausea and, in very rare cases (0.5 per 10,000 in testing facilities such as exercise laboratories, hospitals and physician offices), heart rhythm disturbances or heart attack. While serious risk to healthy participants is highly unlikely, you should understand the risks and either accept them or choose not to participate in this study.

All the exercise tests will be conducted by qualified laboratory personnel under the supervision of the researchers. Research personnel are trained to handle identifiable risks and emergencies, and have certification in CPR. The PAR-Q+ health-screening questionnaire will help to identify any risk factors related to exercise.

The experimental protocols will require a high level of effort that most people find challenging. You will be monitored continuously to ensure you are responding appropriately and we will ensure that you can safely complete the experimental trials. It is important to remember that you can stop any part of the study at any time.

There is a small risk of muscle strain from either the exercise challenges or from carrying and wearing the occupational equipment. The equipment is all of excellent quality and we take great care with correct sizing and fitting to minimize any discomfort or possible injury. The boots used in this study are also of excellent quality and we will do everything possible to get the best fit before any strenuous exercise challenge is done. It is important to remember that you can stop any part of the study at any time for any reason including discomfort with any of the procedures or any of the equipment (*e.g.*, duty equipment or boots).

Confidentiality
To ensure confidentiality, personal information will be removed from the data files once the experiment is completed. Data will be coded (names removed) and stored in a locked filing cabinet and/or password protected computer, accessible only to the researchers. Information is normally

kept for five years in secure storage at the University of Alberta after publication and then it is destroyed. Study records may be reviewed by people from the University of Alberta or Research Ethics Board in order to monitor the research.

Freedom to Withdraw
You may withdraw from the study at any time without consequence or hard feelings. If you wish to withdraw from the study, simply notify one of the researchers. If you withdraw before the study is complete, any information that we have collected about you will be destroyed upon your request. If you are a student, withdrawal from the study will not affect your academic status or access to services.

Compensation for Injury
If you become ill or injured as a result of participating in this study, necessary medical treatment will be available at no additional cost to you. By signing this consent form you are not releasing the investigator(s), institution(s) and/or sponsor(s) from their legal and professional responsibilities.

Other Compensation
If you require, a parking coupon can be provided for the study days. At the end of the study, we will be pleased to give you a small gift (*e.g.*, UA t-shirt) to acknowledge your contribution to the research study.

Additional contacts
The plan for this study has been reviewed for its adherence to ethical guidelines by a Research Ethics Board at the University of Alberta.

For questions regarding participant rights and ethical conduct of research, contact the Research Ethics Office at (780) 492-2615.

Thank you for your interest in this study. We appreciate the time you have taken to read this information letter. If you have further questions regarding this study or your participation in it, please contact one of the investigators.

CONSENT FORM

The Impact of Police Equipment on the Cardiopulmonary Responses to Treadmill Exercise and Simulated Police Work

Principal Investigator: Stewart Petersen, PhD

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Faculty of Kinesiology, Sport, and Recreation, 780-492-2213

To be completed by the research participant

Do you understand that you have been asked to be in a research study?

Yes No

Have you read and received a copy of the attached Information Sheet?

Yes No

Do you understand the benefits and risks involved in taking part in this research study?

Yes No

Have you had an opportunity to ask questions and discuss this study?

Yes No

Do you understand that you are free to refuse to participate, or to withdraw from the study at any time, without consequence, and that your information will be withdrawn at your request?

Yes No

Has the issue of confidentiality been explained to you? Do you understand who will have access to your information?

Yes No

This study was explained to be by:___________________________________

I agree to take part in this study:

____

Signature of Research Particpant Printed Name Date

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate.

____

Signature of Investigator or Designee Printed Name Date

THE INFORMATION SHEET MUST BE ATTACHED TO THIS CONSENT FORM AND A COPY OF BOTH FORMS GIVEN TO THE PARTICIPANT.

POLICE STUDY		
FAMILIARIZATION TRIAL		
SUBJECT NAME		DATE
HEIGHT (cm)	MASS (kg)	GEAR MASS (kg)
BOOT SIZE	BODY ARMOR SIZE	BELT SIZE
UNIFORM SHIRT SIZE	UNIFORM PANT SIZE	

TREADMILL EXERCISE (PDE)						COMMENTS/NOTES
TIME	SPEED	GRADE	HR	RPE	BS	
1	3.5	0				
2	3.5	0				
3	3.5	2				
4	3.5	2				
5	3.5	4				
6	3.5	4				
7	3.5	6				
8	3.5	6				
9	3.5	8				
10	3.5	8				

SPIROMETRY PRACTICE							
TRIAL 1		TRIAL 2		TRIAL 3		BEST	
FVC		FVC		FVC		FVC	
FEV_1		FEV_1		FEV_1		FEV_1	
FEV_1/FVC		FEV_1/FVC		FEV_1/FVC		FEV_1/FVC	

INSPIRATORY CAPACITY PRACTICE							
TRIAL 1		TRIAL 2		TRIAL 3		BEST	
IC (L)		IC (L)		IC (L)		IC (L)	

A-PREP CIRCUIT PRACTICE			
TRIAL 1	TRIAL 2		COMMENTS/NOTES
WALKTHROUGH	HR 1st HALF		
	RPE 1st HALF		
	BS 1st HALF		
	HR 2nd HALF		
	RPE 2nd HALF		
	BS 2nd HALF		

POLICE GRADED EXERCISE TEST: PDE (LOADED) / PT (UNLOADED)							
SUBJECT NAME					**DATE**		
HEIGHT (cm)		**BODY MASS (kg)**		**C. MASS (kg)**		**RESTING HR (bpm)**	
TIME (min)	**SPEED (mph)**	**GRADE (%)**	**HR (bpm)**	**EX STRESS**	**BRE STRESS**	**IC**	**$PETCO_2$**
BASELINE 1	**0**	**0**					
2	**0**	**0**					
3	**0**	**0**					
4	**0**	**0**					
EX START 1	**3.5**	**0**					
2		**0**					
3		**2**					
4		**2**					
5		**4**					
6		**4**					
7		**4**					
8		**4**					
9		**4**					
10		**4**					
11		**6**					
12		**6**					
13		**8**					
14		**8**					
15		**10**					
16		**10**					
17		**12**					
18		**12**					
19		**14**					
20		**14**					
21		**16**					
22		**16**					
23		**18**					
24		**18**					
25		**20**					
26		**20**					
27		**22**					
28		**22**					
29		**24**					
30		**24**					
31		**26**					
32		**26**					
		Pre	**Post**	**Ambient temperature**			
Sigl Dis (20s)	**O_2**			**Ambient pressure**			
	CO_2			**Ambient humidity**			

TIME (min)	SPEED (mph)	GRADE (%)	HR (bpm)	EX STRESS	BRE STRESS	IC	$PETCO_2$
32	↓	28					
33		28					
34		30					
35		30					
36		32					
37		32					
		Pre	Post	Ambient temperature			
Sigl Dis (20s)	O_2			Ambient pressure			
	CO_2			Ambient humidity			

POLICE PROJECT		
APREP EXPERIMENTAL TRIALS		
NAME	DATE	MASS
PT MASS	APS MASS	PDE MASS

CONDITION ORDER	#1	#2	#3

PT	
START TIME	
TOTAL TIME	
AVG HR	
RPE #1	BS #1
RPE #2	BS #2
RPE #3	BS #3

APS	
START TIME	
TOTAL TIME	
AVG HR	
RPE #1	BS #1
RPE #2	BS #2
RPE #3	BS #3

PDE	
START TIME	
TOTAL TIME	
AVG HR	
RPE #1	BS #1
RPE #2	BS #2
RPE #3	BS #3

POLICE – Treadmill Protocol Measurement Cycle

GXT Per Stage (Every 2 min, 2% Grade)

1:00 – 1:30 $ETCO_2$

1:30 – 1:40 RPE

1:50 – 2:00 HR

1:50 – 2:00 IC (Watch for completion, do not increase grade until IC's are complete)

Appendix C – Additional Results

Table C-1. Mean (±SE) spirometry results in physical training (PT) and police duty ensemble (PDE) conditions. Tests were conducted standing with minimal forward lean. (n=25)

	PT	PDE
FVC (L)	5.35 (0.20)	5.15 (0.20)*
FEV_1 (L)	4.33 (0.15)	4.19 (0.15)*
FEV_1/FVC	81 (1)	82 (1)
PEFR ($L \cdot s^{-1}$)	9.03 (0.43)	8.90 (0.42)

FVC, forced vital capacity; FEV_1, forced expired volume in 1 second; PEFR, peak expiratory flow rate. * $p<0.05$ compared to PT.

Table C-2. Mean (±SE) task-specific interval difference times (s) during the work simulation. Difference times were calculated by subtracting the previous interval time (s) from the current interval. (n=4)

	Task-Specific Intervals					
Condition	End Run	BCS 1	AR1	BCS 2	AR2	End Victim Drag
PT	37 (±3)	13 (±2)	5 (±1)	13 (±2)	5 (±1)	17 (±2)
WB	37 (±4)	13 (±2)	5 (±1)	14 (±2)	5 (±1)	17 (±2)
PDE	42 (±4)	13 (±2)	5 (±1)	14 (±2)	5 (±1)	20 (±2)

Note: End Run, end of pursuit portion of work simulation; BCS, body-control simulator; AR, arm-restraint simulator.

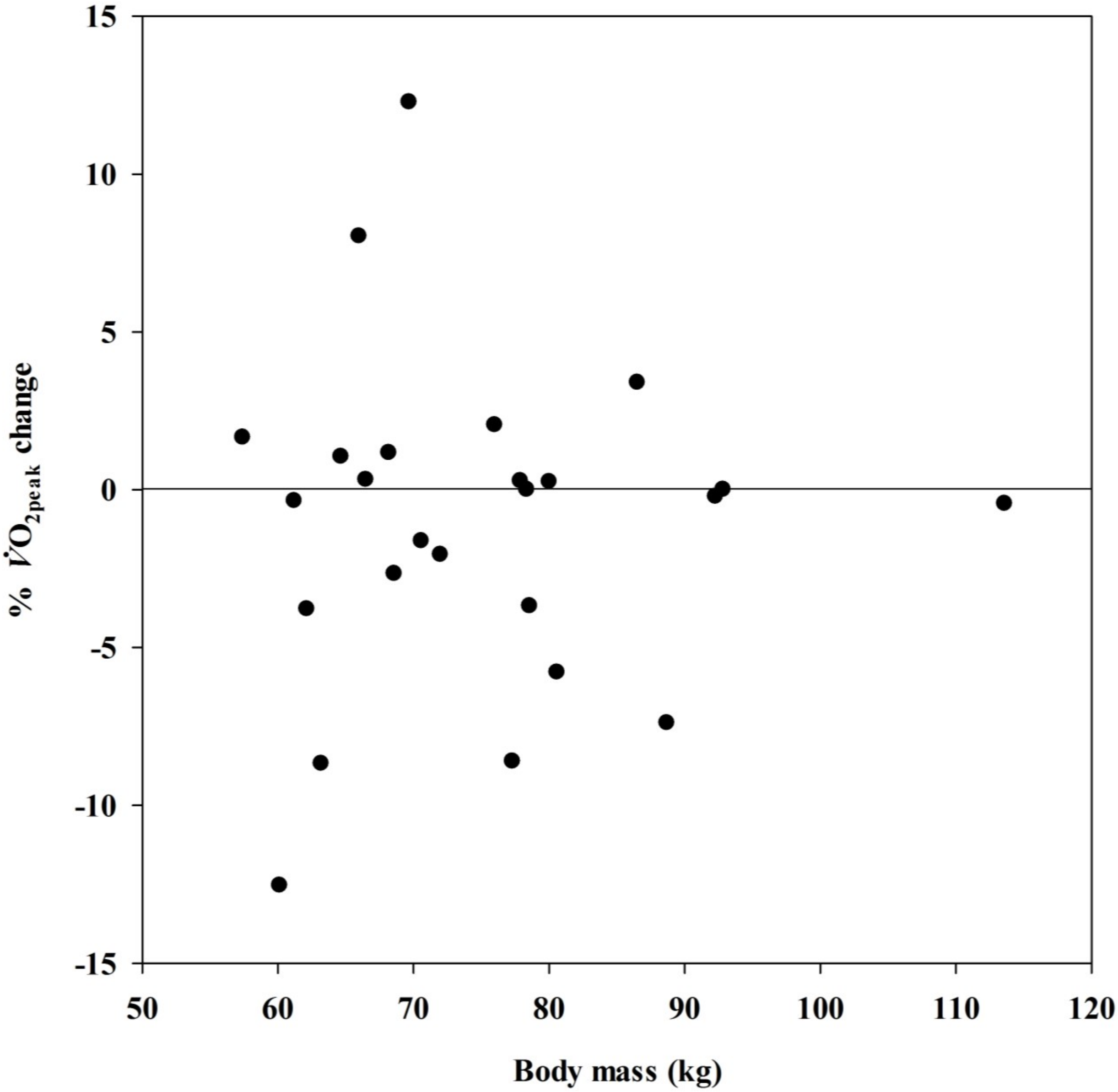

Figure C-1. $\dot{V}O_{2peak}$ change (%) compared to body mass (kg) between graded exercise tests in the PT and PDE conditions. (n=25) PT, physical training; PDE, police duty ensemble.

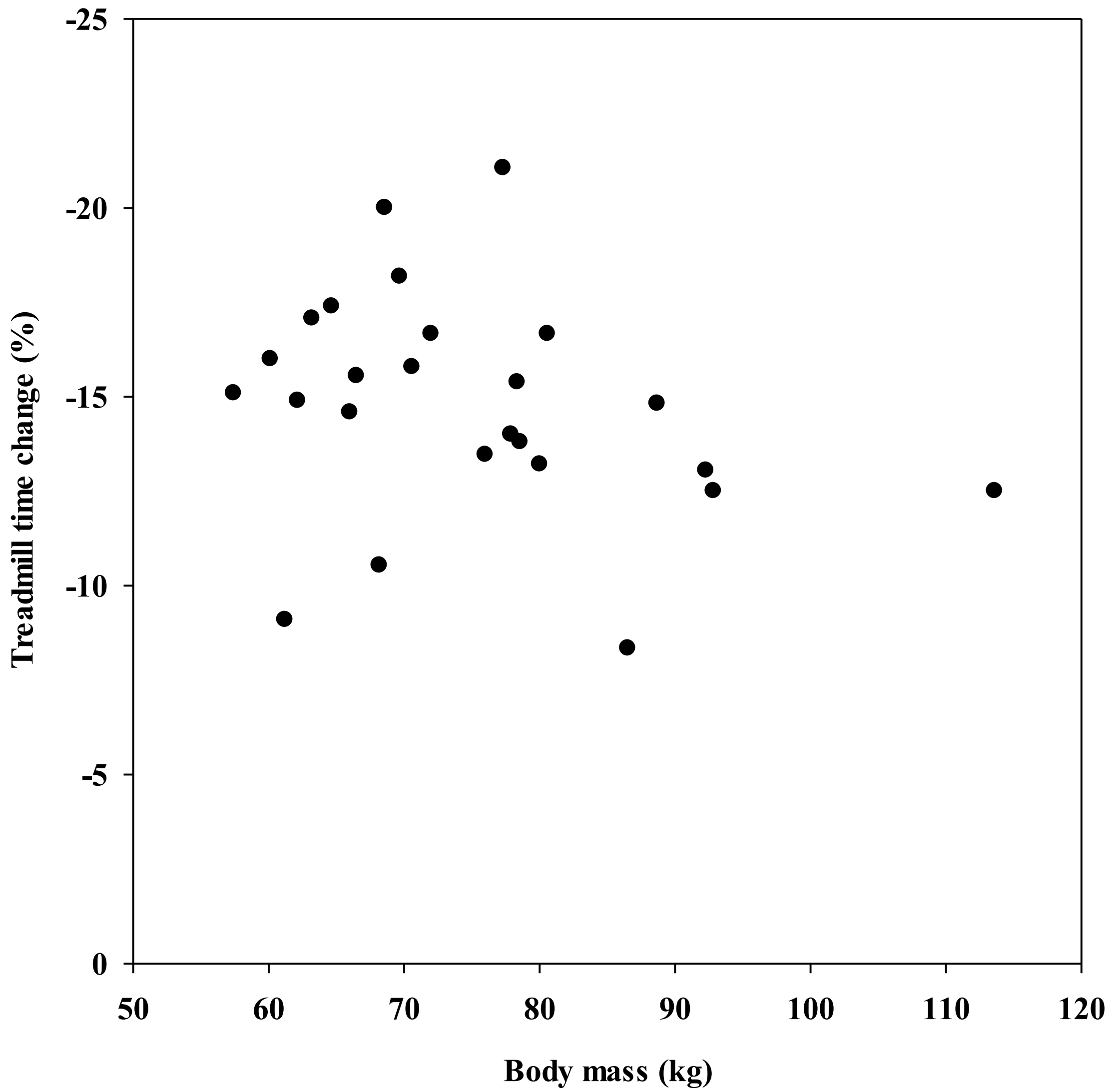

Figure C-2. Treadmill time change (%) in two experimental conditions compared to body mass (kg) during the graded exercise tests. (n=23) PT, physical training; PDE, police duty ensemble.

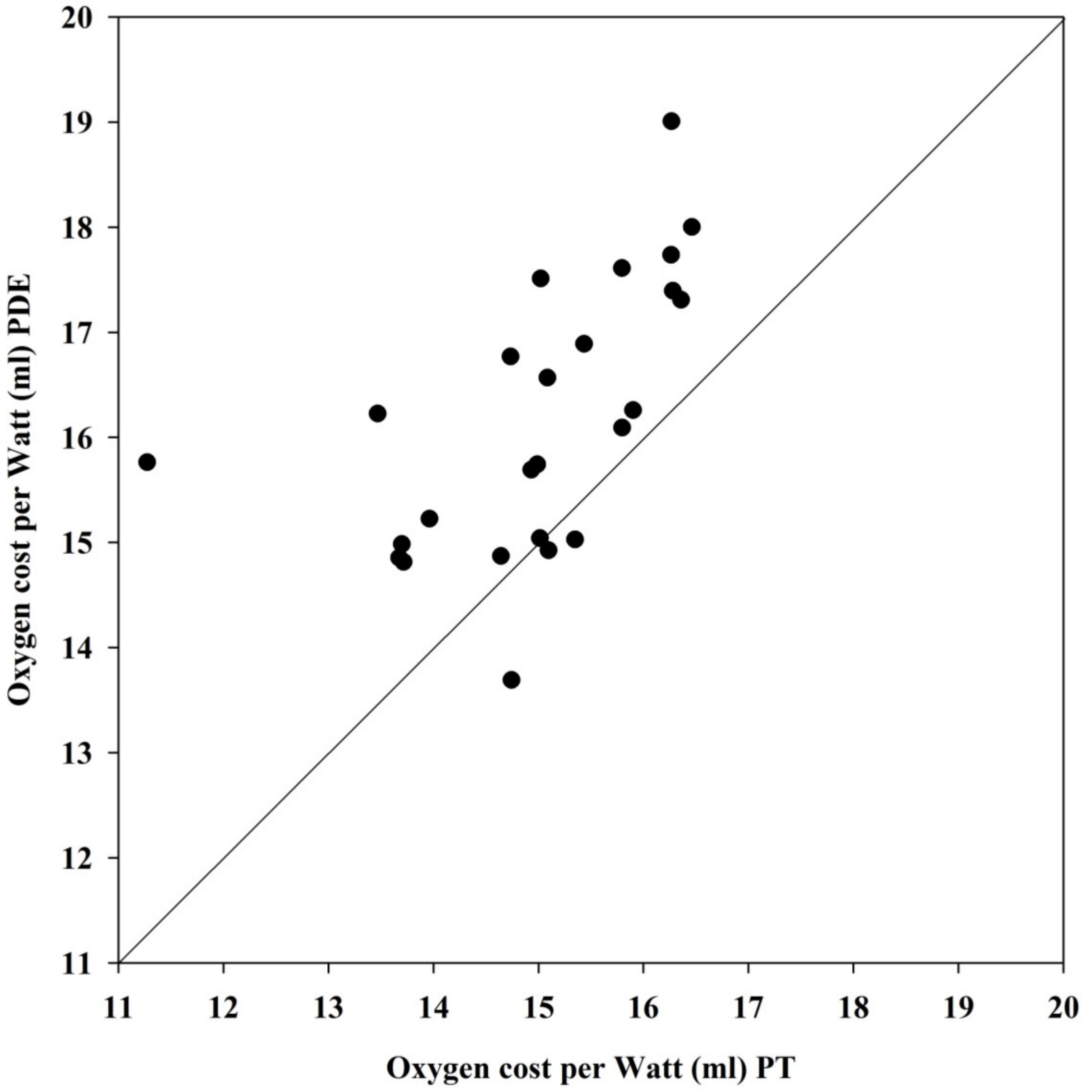

Figure C-3. Net oxygen cost per Watt (ml) during steady-state exercise in two experimental conditions with a line of identity. PT, physical training; PDE, police duty ensemble. (n=25)

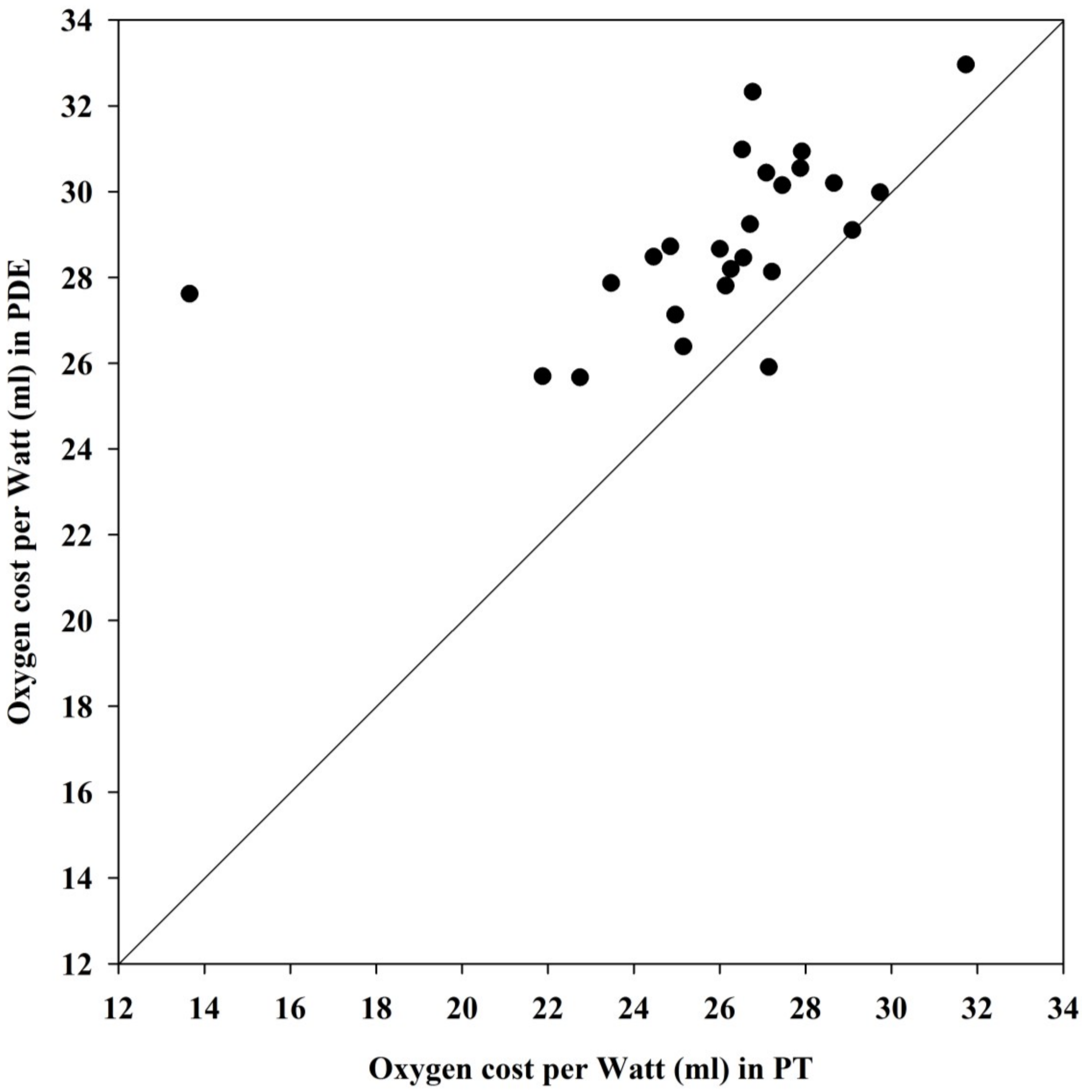

Figure C-4. Net oxygen cost per Watt (ml) at peak exercise in two experimental conditions with a line of identity. PT, physical training; PDE, police duty ensemble. (n=25)

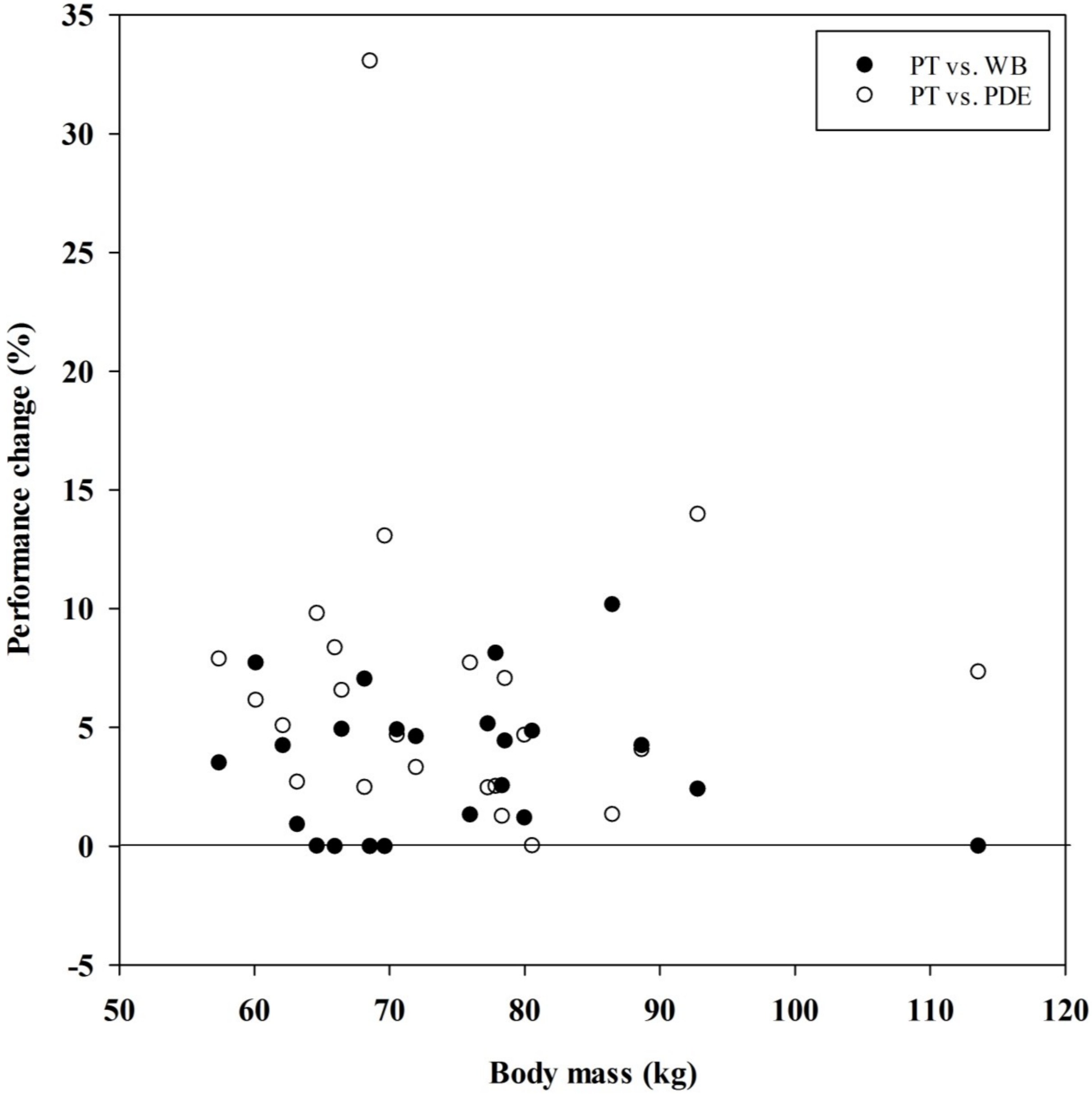

Figure C-5. Performance change (%) in two experimental conditions compared to body mass (kg) during the work simulation. (n=23) PT, physical training; WB, weight belt; PDE, police duty ensemble.

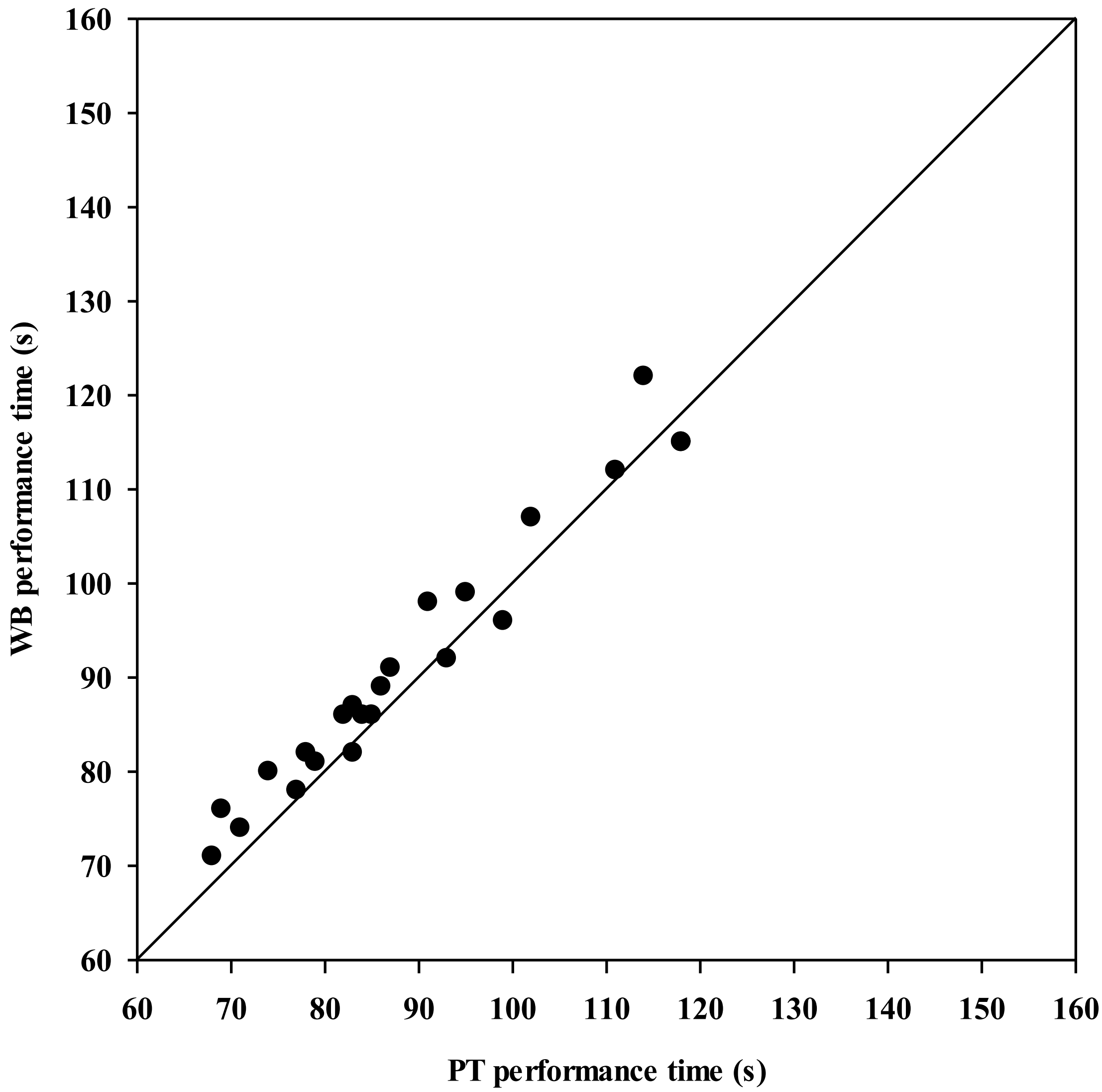

Figure C-6. Performance time (s) on the Alberta Physical Readiness Evaluation for Police circuit in two experimental conditions with a line of identity. PT, physical training; WB, weight belt. (n=23)

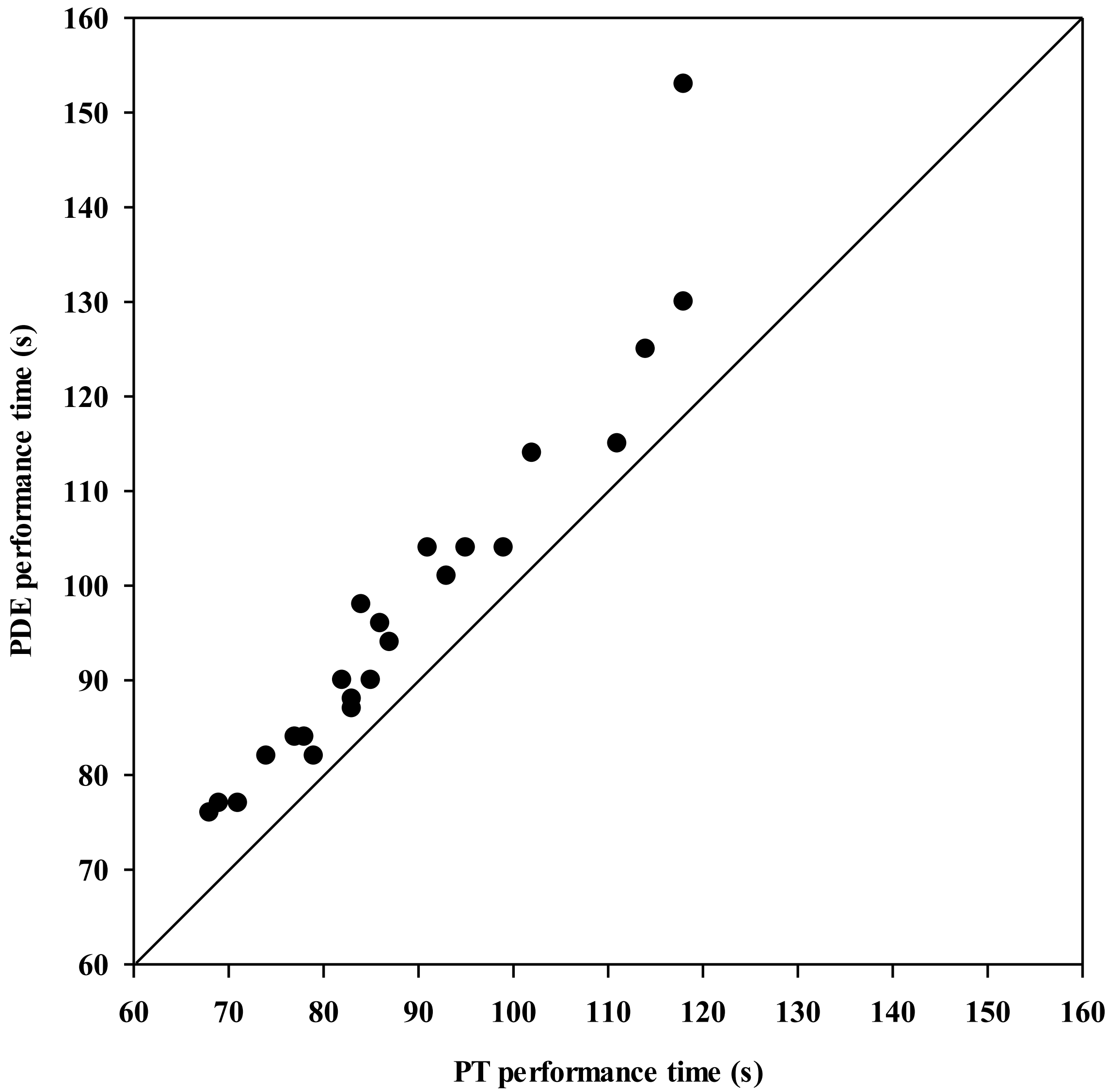

Figure C-7. Performance time (s) on the Alberta Physical Readiness Evaluation for Police circuit in two experimental conditions with a line of identity. PT, physical training; PDE, police duty ensemble. (n=23)

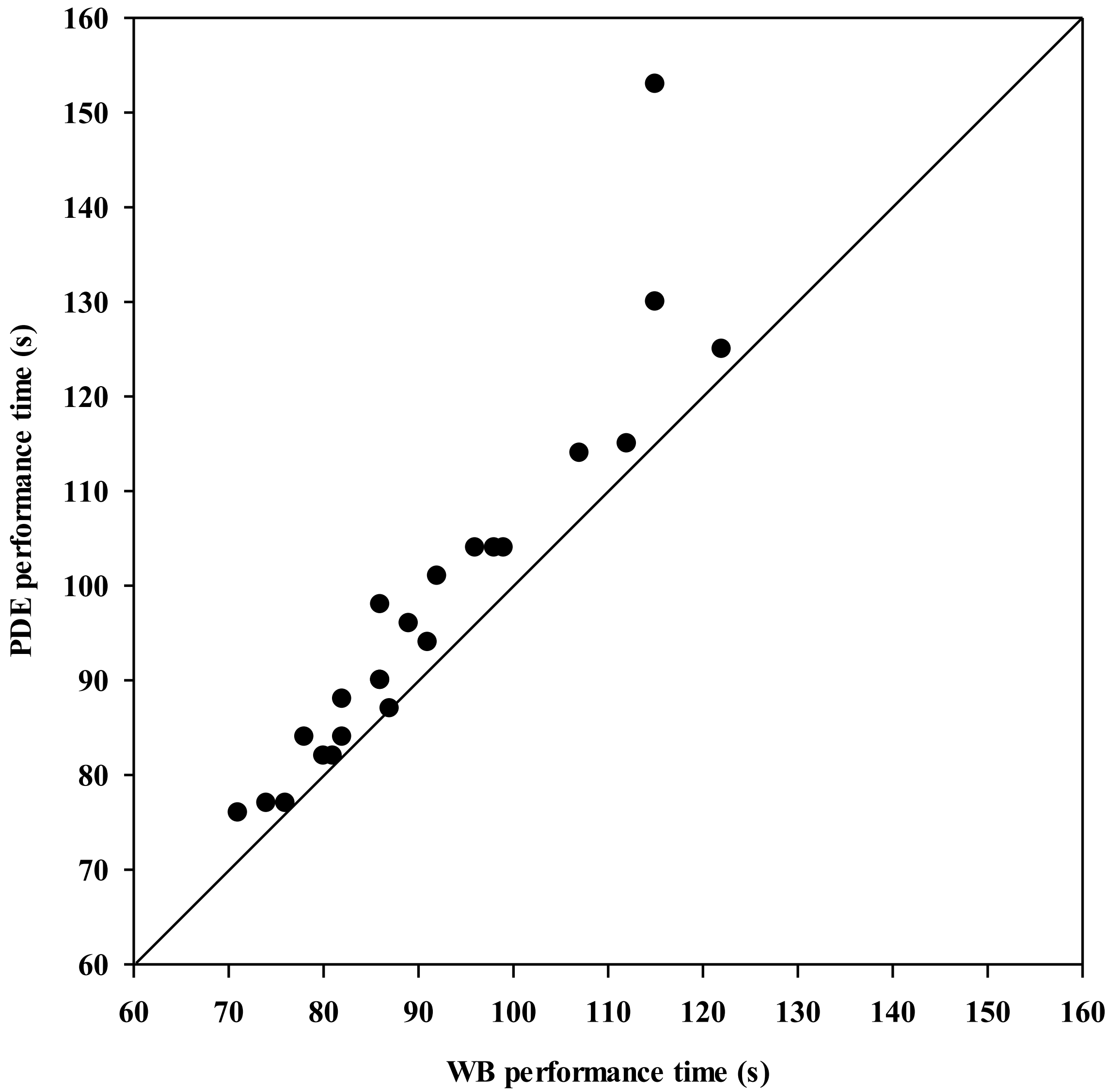

Figure C-8. Performance time (s) on the Alberta Physical Readiness Evaluation for Police circuit in two experimental conditions with a line of identity. WB, weight belt; PDE, police duty ensemble. (n=23)

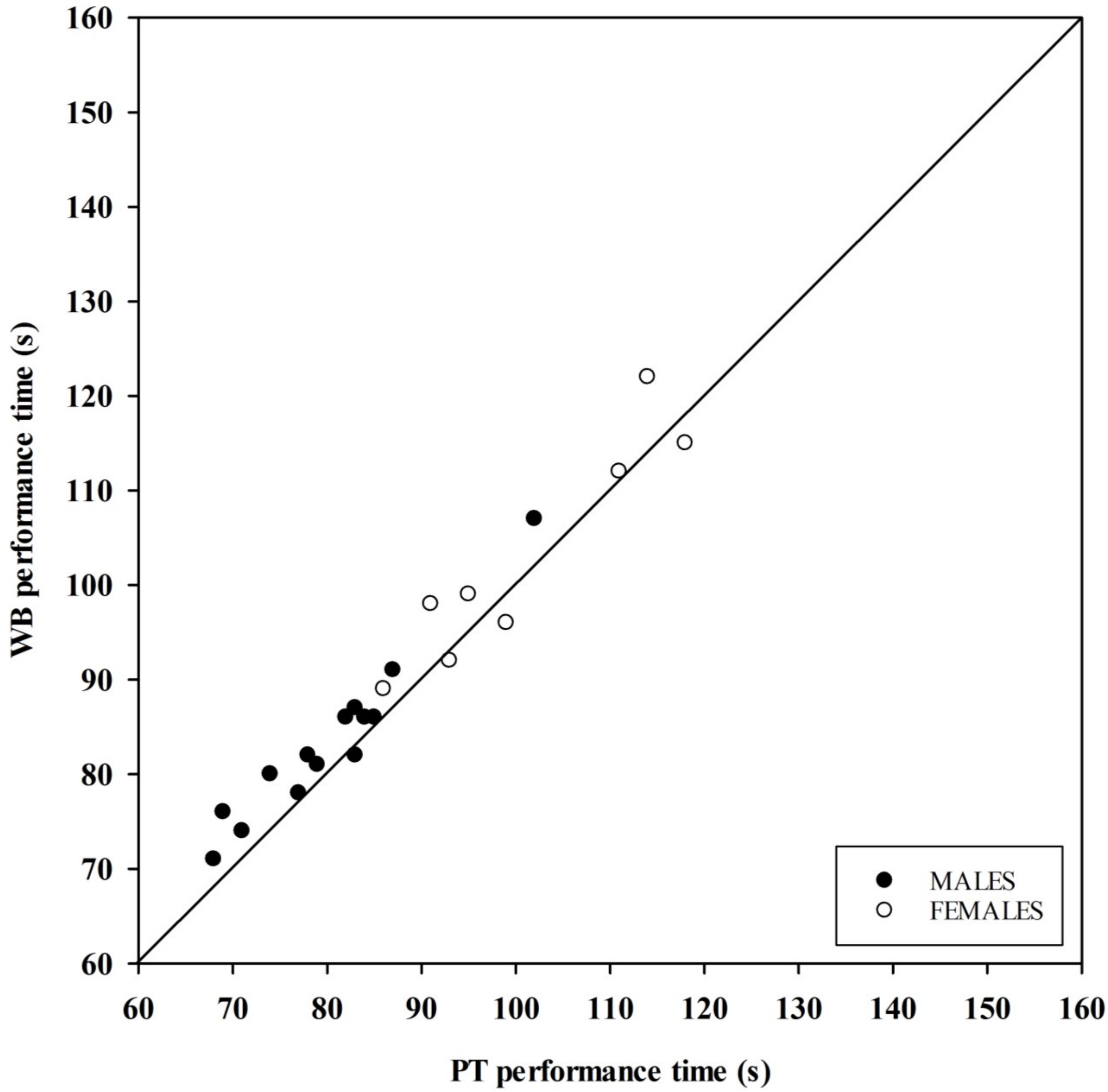

Figure C-9. Performance time (s) on the Alberta Physical Readiness Evaluation for Police circuit in two experimental conditions with a line of identity. PT, physical training; WB, weight belt. (n=23)

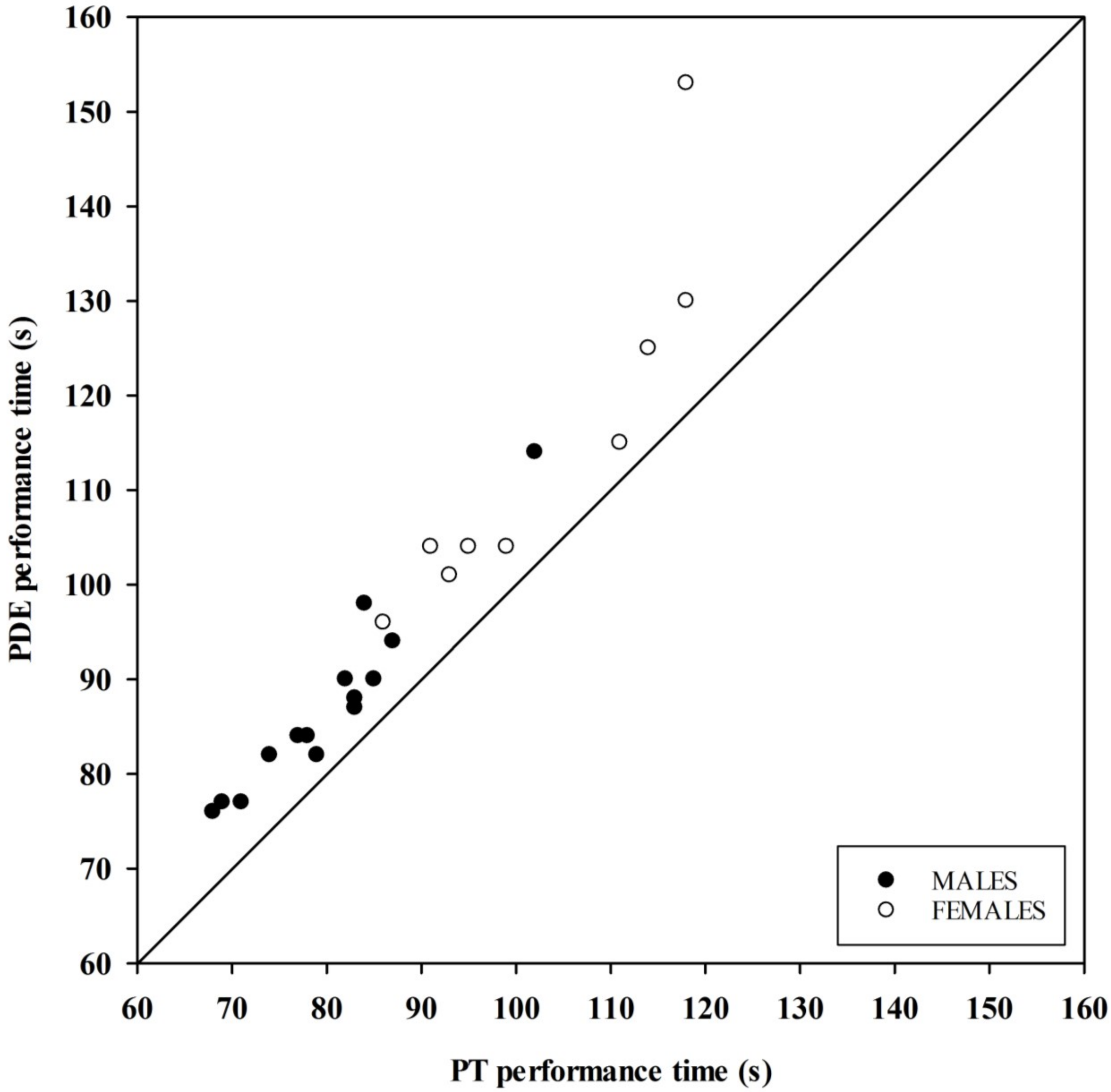

Figure C-10. Performance time (s) on the Alberta Physical Readiness Evaluation for Police circuit in two experimental conditions with a line of identity. PT, physical training; PDE, police duty ensemble. (n=23)

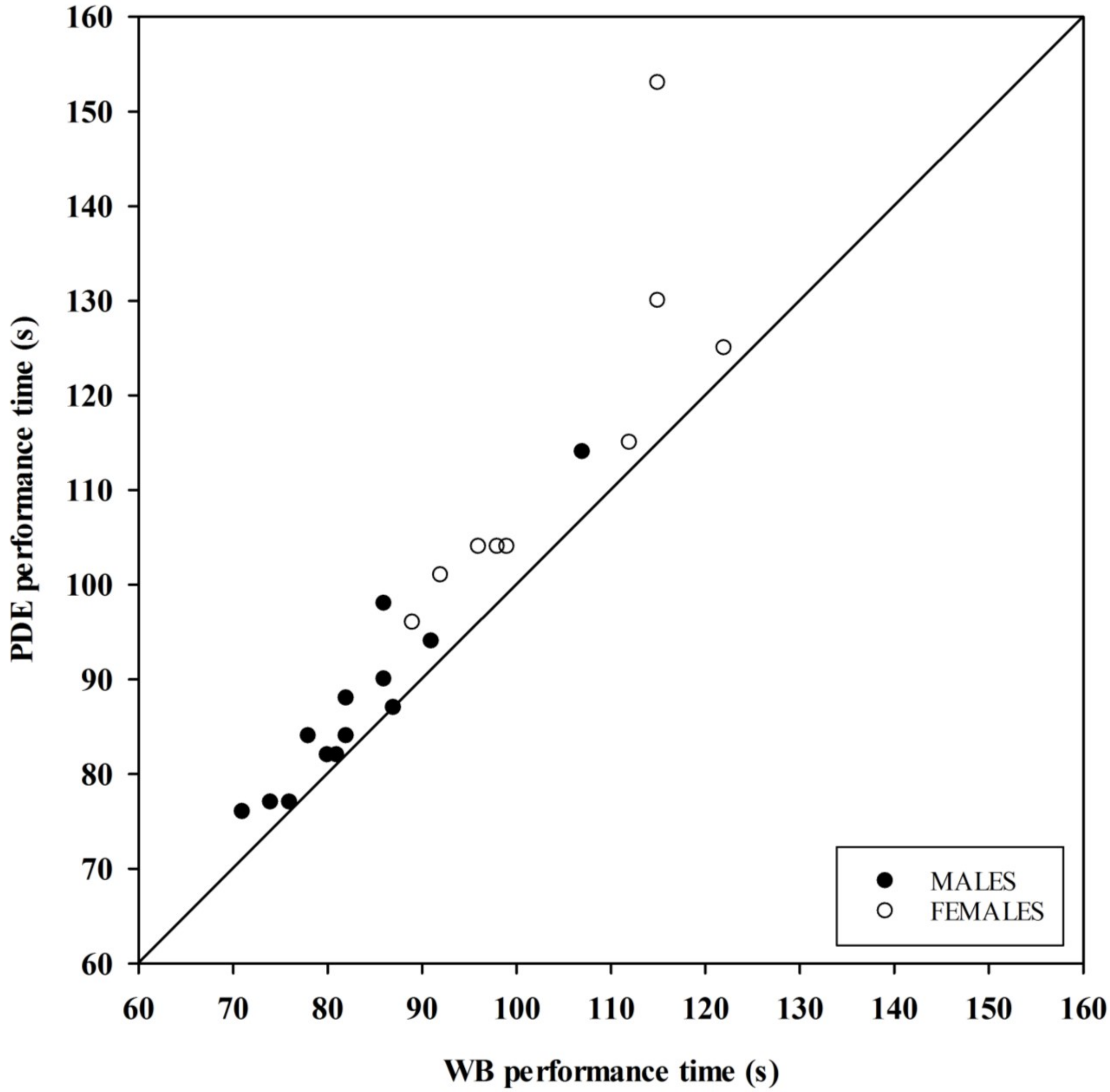

Figure C-11. Performance time (s) on the Alberta Physical Readiness Evaluation for Police circuit in two experimental conditions with a line of identity. WB, weight belt; PDE, police duty ensemble. (n=23)

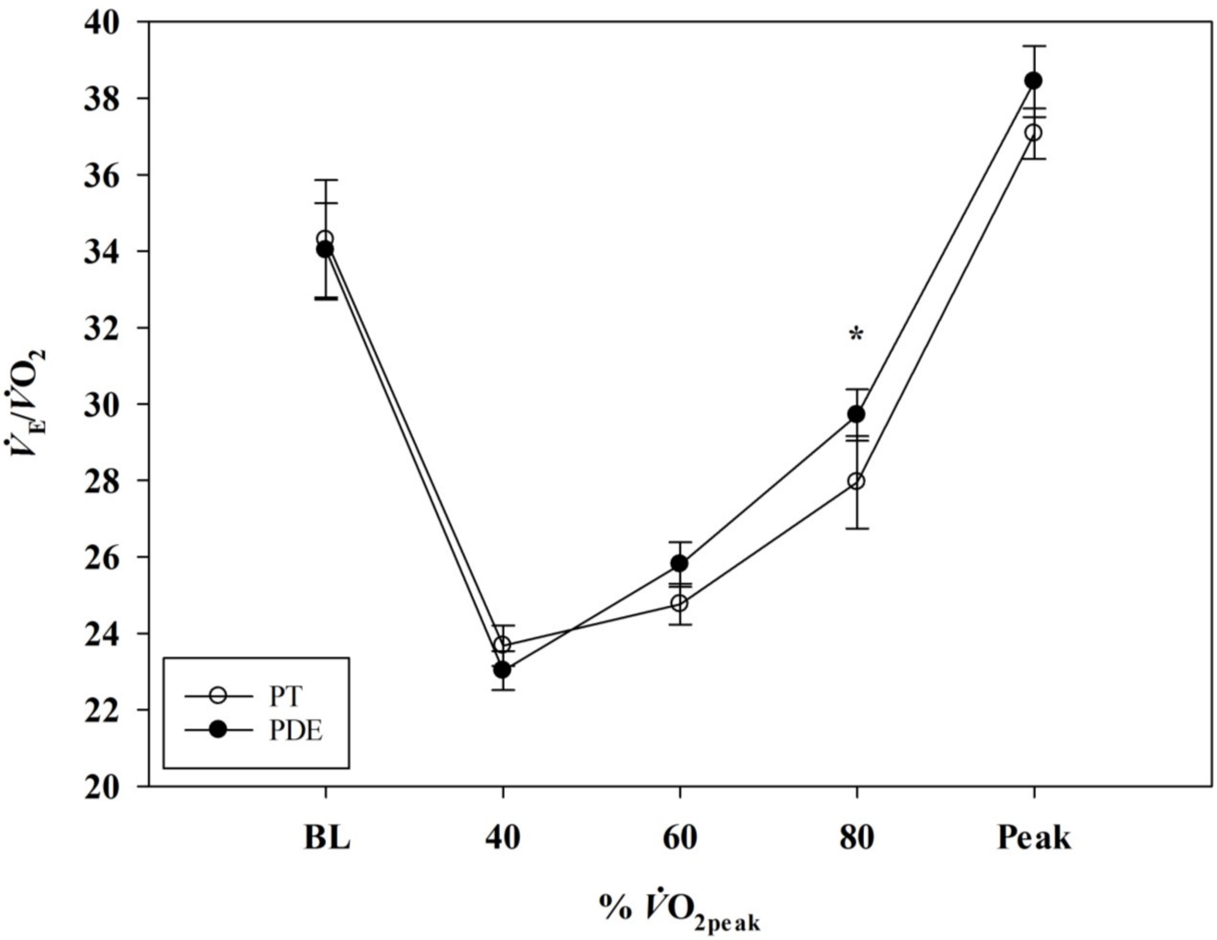

Figure C-12. Mean (±SE) $\dot{V}_E/\dot{V}O_2$ during graded exercise tests in two conditions. PT, physical training; PDE, police duty ensemble; BL, baseline. (n=25); * $p<0.05$.

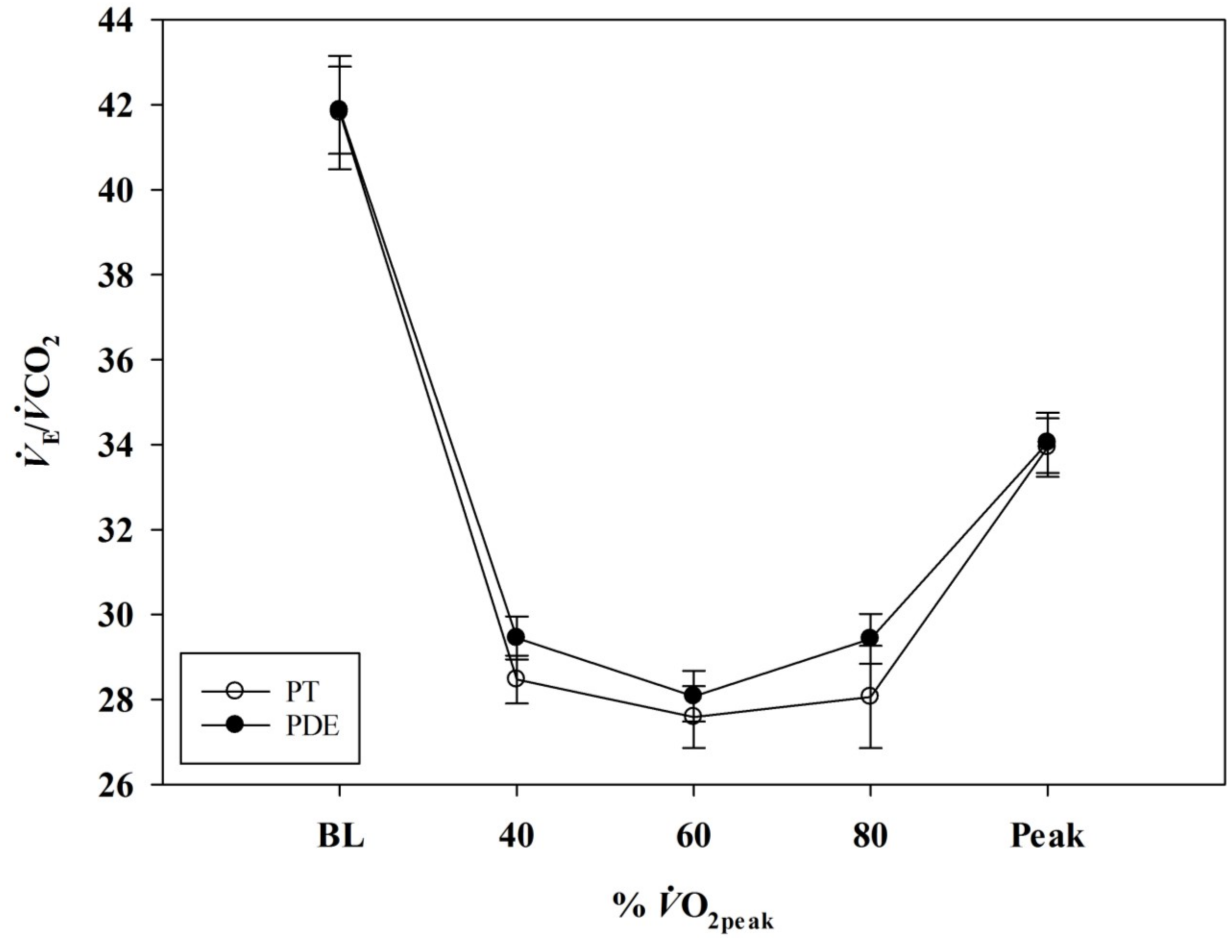

Figure C-13. Mean (±SE) $\dot{V}_E/\dot{V}CO_2$ during graded exercise tests in two conditions. PT, physical training; PDE, police duty ensemble; BL, baseline. (n=25); * p<0.05.

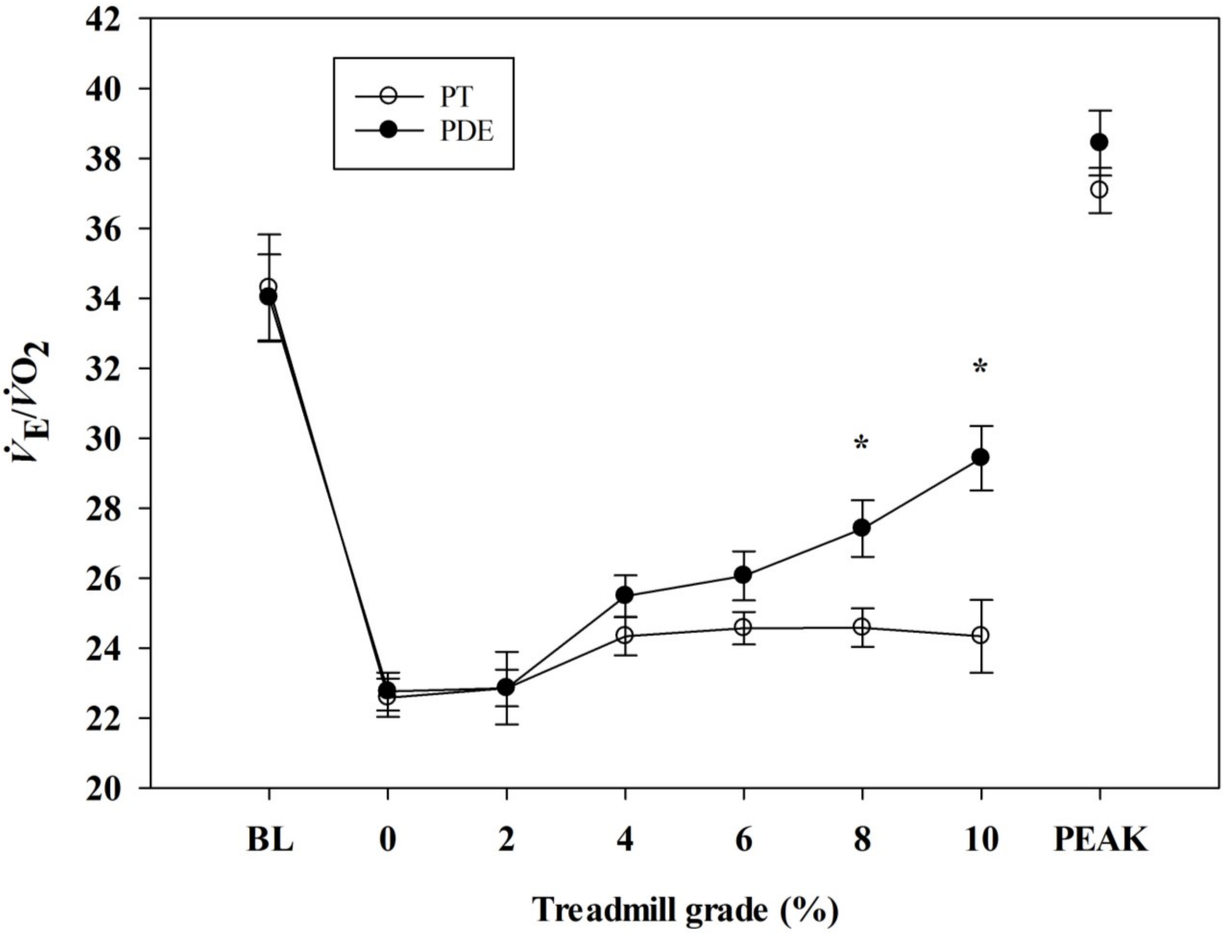

Figure C-14. Mean (±SE) $\dot{V}_E/\dot{V}O_2$ in two conditions on a graded exercise test walking on a motorized treadmill at 93.9 m·min^{-1}. PT, physical training; PDE, police duty ensemble. (n=25); * p<0.05 compared to PT condition.

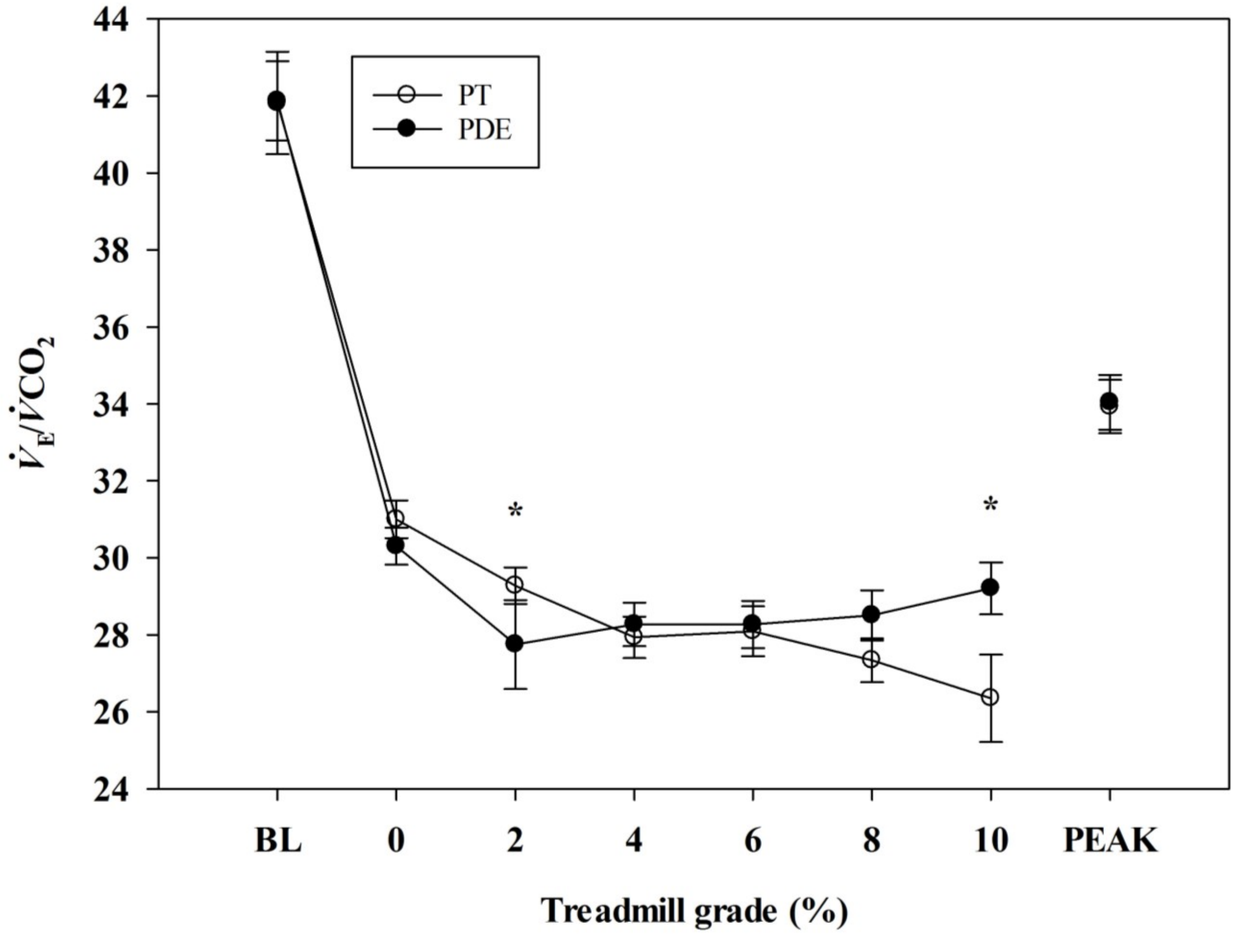

Figure C-15. Mean (±SE) $\dot{V}_E/\dot{V}CO_2$ in two conditions on a graded exercise test walking on a motorized treadmill at 93.9 m·min^{-1}. PT, physical training; PDE, police duty ensemble. (n=25); * p<0.05 compared to PT condition.

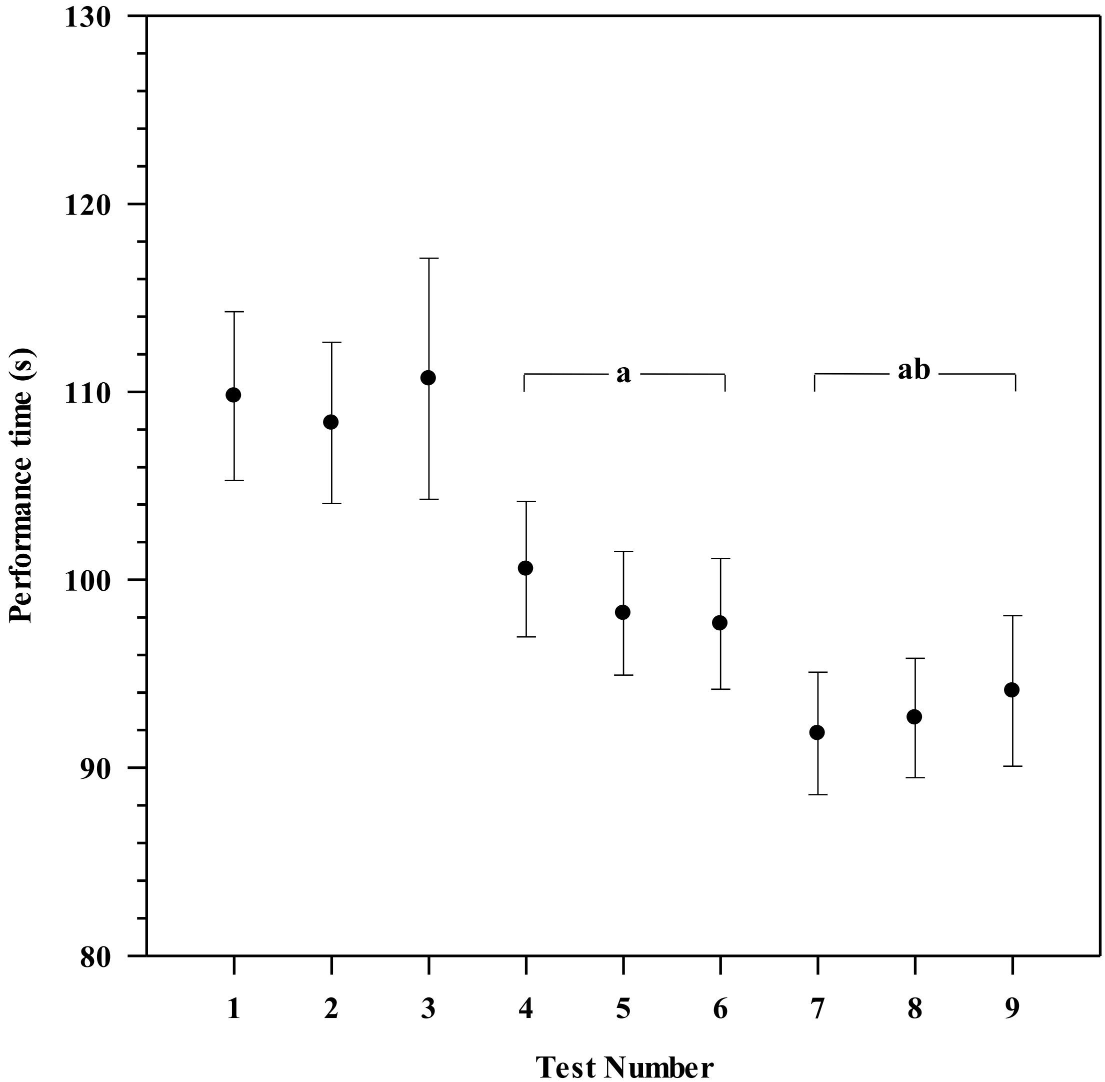

Figure C-16. Performance time (s) in nine repetitions of the Alberta Physical Readiness Evaluation for Police circuit. Tests were distributed over three testing sessions on three separate days with three repetitions per day. Tests were bracketed by a standardized warm-up and recovery. (n=23) [a] $p<0.05$ compared to previous three tests; [b] $p<0.05$ compared to tests 1-3.

Appendix D – Statistical Considerations

In order to address the apparent trends that appear in the data from this thesis at peak exercise, this appendix highlights post-hoc statistical considerations for confirming the efficacy of our statistical analysis.

Effect sizes were calculated post-hoc with the formula:

$$\text{Cohen's } d = (Mean_1 - Mean_2) / SD_{pooled}$$

D.1 Treadmill Effect Sizes and Post-hoc Achieved Power

$\dot{V}O_2$ ($L \cdot min^{-1}$) Effect Size = 0.05. Power of t-test (two-tailed) = 0.28.

$\dot{V}_E$ ($L \cdot min^{-1}$) Effect Size = 0.05. Power of t-test (two-tailed) = 0.12.

Breathing Frequency ($breaths \cdot min^{-1}$) Effect Size = 0.28. Power of t-test (two-tailed) = 0.43.

Tidal Volume (L) Effect Size = 0.14. Power of t-test (two-tailed) = 0.42.

D.2 Work Simulation Effect Sizes

PT vs. PDE Effect Size = 0.52.

PT vs. WB Effect Size = 0.17.

One-Way Repeated Measures ANOVA Power of Performed Test With $a = 0.05$: 1.00.

D.3 Sample Sizes Required to Detect Changes of Similar Magnitude in Key Variables

Detecting a Change in $\dot{V}O_2$ ($L \cdot min^{-1}$) at PEAK

Sample Size = 94

Difference in Means = 0.05

Expected Standard Deviation of Change = 0.17

Power = 0.80

Alpha = 0.05

Detecting a Change in $\dot{V}_E$ ($L \cdot min^{-1}$) at PEAK

Sample Size = 293

Difference in Means = 2.00

Expected Standard Deviation of Change = 12.16

Power = 0.80

Alpha = 0.05

Detecting a Change in Breathing Frequency ($breaths \cdot min^{-1}$) at PEAK

Sample Size = 45

Difference in Means = 3.00

Expected Standard Deviation of Change = 6.96

Power = 0.80

Alpha = 0.05

Detecting a Change in Tidal Volume (L) at PEAK

Sample Size = 63

Difference in Means = 0.09

Expected Standard Deviation of Change = 0.25

Power = 0.80

Alpha = 0.05

Appendix D – References

Cohen, J. 1988. Statistical power analysis for the behavioral sciences (2nd ed.). Lawrence Earlbaum Associates, Hillsdale, NJ.