Factors related to musculoskeletal disorders in Swedish police

Louise Bæk Larsen
Abstract

**Background:** Musculoskeletal disorders are a major problem in the adult working population and are the most frequently reported cause of work-related disease in many countries. Police working in active duty are subject to occupation-specific exposures in the workplace which could place them at an increased risk of developing musculoskeletal disorders. These exposures include the requirement to wear a duty belt and body armour as well as sitting for long periods in fleet vehicles.

It is well recognised that the development of musculoskeletal disorders is multifactorial and that both physical and psychosocial workplace factors must be considered when addressing this issue.

**Aim:** The overall aim of this thesis was to increase knowledge relating to musculoskeletal disorders in Swedish police by exploring the prevalence of pain and its relationship to physical and psychosocial factors in the work environment.

**Methods:** Studies included in this thesis were conducted using different quantitative methods. Studies I and II were based on data from a self-administered online survey, distributed to all police officers working in active duty. Descriptive statistics and regression analyses were used to document the prevalence of musculoskeletal pain and the effects of exposure variables (physical and psychosocial) and covariates on multi-site pain. Study III was conducted using a three-dimensional gait analysis system incorporating two force plates to explore the effect of different load carriage systems on kinematic and kinetic variables. These included: a) a standard load carriage condition, incorporating duty belt and body armour, b) an alternate load carriage condition, incorporating thigh holster, load-bearing vest and body armour, and c) a control condition in which no equipment was worn. Study IV included the same three conditions as in Study III but investigated sitting postures and comfort. A pressure mat was utilised to determine contact pressure and contact area while sitting in and driving police vehicles while a survey was used to measure experienced discomfort related to vehicle seat, in vehicle tasks and in specific body regions after driving police fleet vehicles. Non-parametric statistical tests were used to investigate differences between load carriage conditions in Studies III and IV.
Results: The results of this thesis revealed that the most frequently reported musculoskeletal disorder among Swedish police working in active duty was lower back pain (43.2%) and that multi-site musculoskeletal pain (41.3%) was twice as prevalent as single-site pain (19.7%). The results from regression analyses showed that both physical and psychosocial workplace factors were associated with an increase in the odds ratio (OR) for multi-site musculoskeletal pain. The physical workplace factor with the greatest association to multi-site musculoskeletal pain was found for individuals reporting discomfort experienced from wearing duty belts (OR 5.42 (95% CI 4.56 – 6.43)). The psychosocial workplace factor with the greatest association to multi-site musculoskeletal pain was found for individuals reporting high-strain jobs (OR 1.84 (95% CI 1.51 – 2.24)). When investigating the effect of different load carriage conditions on gait kinematic and kinetics, it was demonstrated that wearing body armour, or body armour combined with a load-bearing vest, resulted in less rotation of the trunk when compared to not wearing any equipment. It was also found that wearing a thigh holster and load-bearing vest allowed for a greater range of rotation in the right hip compared to the standard load-bearing condition, which incorporated a belt-mounted hip holster. Kinetics of the ankle joints were greater for both load carriage conditions compared to the control condition. Discomfort ratings revealed a clear preference for the alternate load-carriage condition incorporating a thigh holster and a load-bearing vest. After driving, the greatest level of discomfort was reported when wearing the duty belt in the standard load carriage condition (36; IQR 14 - 52 mm). The lower back was found to be the body region with most experienced discomfort (30.5; IQR 11 - 42 mm). Pressure data demonstrated that wearing a thigh holster and load-bearing vest resulted in less pressure in the lower back when compared to the standard load carriage condition. At the same time, contact pressure in the upper back increased followed by a decrease in contact area.

Conclusion: Musculoskeletal pain is a considerable problem among Swedish police with lower back pain being the most frequently reported. Multi-site musculoskeletal pain was found to be more common than single-site pain and both physical and psychosocial factors were associated to multi-site musculoskeletal pain. Of the exposures studied in this thesis, duty belts and high strain jobs were found to have the greatest association to musculoskeletal pain.
The use of load-bearing vest and thigh holster were found to affect levels of discomfort especially while driving. Also range of motion in the trunk and right hip was affected by wearing mandatory equipment.
List of papers

This thesis is based on the following four papers, which are referred to by their Roman numerals in the text:

Paper I

Paper II

Paper III

Paper IV

The articles have been reprinted with the kind permission of respective journals.
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbreviations</td>
<td>9</td>
</tr>
<tr>
<td>Definitions</td>
<td>10</td>
</tr>
<tr>
<td>Preface</td>
<td>11</td>
</tr>
<tr>
<td>Introduction</td>
<td>12</td>
</tr>
<tr>
<td>Background</td>
<td>15</td>
</tr>
<tr>
<td>Police</td>
<td>15</td>
</tr>
<tr>
<td>Work environment of the police</td>
<td>15</td>
</tr>
<tr>
<td>Musculoskeletal disorders and pain</td>
<td>17</td>
</tr>
<tr>
<td>Development of musculoskeletal disorders</td>
<td>18</td>
</tr>
<tr>
<td>Policies and guidelines regulating the work environment</td>
<td>20</td>
</tr>
<tr>
<td>Theoretical framework</td>
<td>21</td>
</tr>
<tr>
<td>Rationale</td>
<td>25</td>
</tr>
<tr>
<td>Aim</td>
<td>27</td>
</tr>
<tr>
<td>Methods and material</td>
<td>28</td>
</tr>
<tr>
<td>Design</td>
<td>28</td>
</tr>
<tr>
<td>Participants</td>
<td>30</td>
</tr>
<tr>
<td>Instruments and data collection</td>
<td>31</td>
</tr>
<tr>
<td>Study I and II</td>
<td>31</td>
</tr>
<tr>
<td>Study III</td>
<td>32</td>
</tr>
<tr>
<td>Study IV</td>
<td>34</td>
</tr>
<tr>
<td>Variables of main interest</td>
<td>36</td>
</tr>
<tr>
<td>Studies I and II</td>
<td>36</td>
</tr>
<tr>
<td>Study III and IV</td>
<td>38</td>
</tr>
<tr>
<td>Data analysis</td>
<td>39</td>
</tr>
<tr>
<td>Study I</td>
<td>39</td>
</tr>
<tr>
<td>Study II</td>
<td>40</td>
</tr>
<tr>
<td>Study III</td>
<td>40</td>
</tr>
</tbody>
</table>
Study IV ............................................................................................................ 41
Ethical considerations .......................................................................................... 43
Results .................................................................................................................. 44
  Multi-site musculoskeletal pain (Studies I and II) ............................................ 44
  Gait biomechanics (Study III) ........................................................................... 45
  Discomfort and pressure while driving (Study IV) ......................................... 45
Discussion .......................................................................................................... 47
  General discussion of the results ...................................................................... 47
    Musculoskeletal pain in Swedish police .......................................................... 48
    External load ..................................................................................................... 49
  Organisational and social context factors ......................................................... 53
Methodological discussion .................................................................................. 55
  Musculoskeletal pain in Swedish police .......................................................... 56
  External loads ..................................................................................................... 58
  Organisational and social context factors ......................................................... 60
Conclusion .......................................................................................................... 61
Further research .................................................................................................. 62
Svensk sammanfattning ....................................................................................... 63
Acknowledgements .............................................................................................. 68
References .......................................................................................................... 70
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASDQ</td>
<td>Automobile seat discomfort questionnaire</td>
</tr>
<tr>
<td>ASIS</td>
<td>Anterior superior iliac spine</td>
</tr>
<tr>
<td>CI</td>
<td>Confidence Interval</td>
</tr>
<tr>
<td>EMG</td>
<td>Electromyography</td>
</tr>
<tr>
<td>IASP</td>
<td>International Association for the Study of Pain</td>
</tr>
<tr>
<td>ILO</td>
<td>International Labour Organisation</td>
</tr>
<tr>
<td>JDC</td>
<td>Job Demand Control model</td>
</tr>
<tr>
<td>MSD</td>
<td>Musculoskeletal disorders</td>
</tr>
<tr>
<td>NRC</td>
<td>National Research Council</td>
</tr>
<tr>
<td>OR</td>
<td>Odds Ratio</td>
</tr>
<tr>
<td>ROM</td>
<td>Range of motion</td>
</tr>
<tr>
<td>SWEA</td>
<td>Swedish Work Environment Authority</td>
</tr>
<tr>
<td>SWES</td>
<td>Swedish Work Environment Survey</td>
</tr>
<tr>
<td>WHO</td>
<td>World Health Organisation</td>
</tr>
</tbody>
</table>
## Definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appointments</td>
<td>The equipment normally carried in, for example, the duty belt of police officers including: weapon, baton, torch, handcuffs, extra ammunition, OC spray and radio.</td>
</tr>
<tr>
<td>Kinematics</td>
<td>The description of motion of bodies or objects without reference to mass or force involved.</td>
</tr>
<tr>
<td>Kinetics</td>
<td>The study of force, moments, masses and acceleration but without detailed knowledge of the position or orientation of the bodies or objects involved.</td>
</tr>
<tr>
<td>Load carriage</td>
<td>The system used for carrying police appointments, which, in this thesis, is the duty belt or load-bearing vest and thigh holster.</td>
</tr>
<tr>
<td>Mandatory equipment</td>
<td>The load carriage system and body armour worn by police officers as a part of uniform regulations.</td>
</tr>
<tr>
<td>Pressure</td>
<td>The amount of force applied perpendicular to the surface of an object per unit area.</td>
</tr>
</tbody>
</table>
Preface

During 2011, the individual responsible for the physical work environment of the Swedish police approached Jönköping University with a request to investigate different design solutions for the load carriage used by uniformed police working in active duty. At this point in time, it was the general perception within the police force that musculoskeletal disorders experienced by the Swedish police were related to the use of duty belts and body armour, but no evidence had been collected to support this premise. The initial task assigned by the Swedish Police Authority was to identify and test alternate load carriage designs and to explore the option of relocating appointments carried in the duty belt to a load-bearing vest and thigh holster. With my background as a certified prosthetist/orthotist, and experience working in a gait laboratory using biomechanical tools to measure human movement, it became obvious to me that biomechanical instruments could be one way to analyse different load carriage systems used by the police. Therefore, the initial ideas for this thesis had a biomechanical perspective, which later developed into also including epidemiological research methods.

A collaboration between the School of Health and Welfare at Jönköping University and the Swedish Police Authority was formally initiated in 2012. This collaboration included myself as a doctoral student and a whole new world of learning and trying to understand the work of the Swedish police. This collaboration has given me the opportunity to follow uniformed police in their daily work, meet police and discuss their perceptions of their work environment, and provided access to participants and equipment. Throughout the project, I have worked closely with a reference group which comprised employees of the Swedish Police. This group of individuals has always been available to answer my questions and their critique and discussions have been crucial for the development of this thesis.
Introduction

As part of a mandatory uniform policy which requires the use of body armour and a load carriage system (e.g. duty belt), the police are exposed to external forces which could place them at an increased risk of developing musculoskeletal disorders (Brown, Wells, Trottier, Bonneau, & Ferris, 1998; A. K. Burton, Tillotson, Symonds, Burke, & Mathewson, 1996; Filtness, Mitsopoulos-Rubens, & Rudin-Brown, 2014; Ramstrand & Larsen, 2012). Musculoskeletal disorders are the most frequently reported work-related disorder among Swedish female police (33%) and the third most frequent among male police (24%) (Arbetsmiljöverket, 2009). As such, they constitute a major global health problem which affects the health and wellbeing of the individual and can lead to an increased economic cost for society (Vos, Abajobir, Abate, & KM, 2017).

The most common problems arising from musculoskeletal disorders are lower back and neck pain, which are still poorly understood conditions (Storheim & Zwart, 2014). The extent to which musculoskeletal disorders are caused by work conditions has, for decades, been a topic of discussion. It is, however, accepted that both work-related and non-work-related factors are associated with the development of musculoskeletal disorders (National Research Council, 2001). Non-work-related factors include individual factors, activities undertaken during leisure time and lifestyle factors, while work-related factors include physical, psychological, organisational and social aspects of work.

Most studies investigating the effects of load carriage have been conducted on military personnel and hikers, with a focus on backpack weight and design (S. A. Birrell & Haslam, 2010; Stewart A. Birrell, Hooper, & Haslam, 2007; Golriz & Walker, 2011; LaFiandra, Wagenaar, Holt, & Obusek, 2003). While these studies have confirmed that both variables are related to musculoskeletal disorders, limited attention has been directed to other types of load carriage systems such as those used by the police (Dempsey, Handcock, & Rehrer, 2013; Lewinski, Dysterheft, Dicks, & Pettitt, 2015; Ramstrand, Zugner, Larsen, & Tranberg, 2016). Currently, there are differing opinions as to whether the police have a higher prevalence of musculoskeletal disorders than the general population (Brown et al., 1998; T. S. Cho, Jeon, Lee, Seok, & Cho,
There is also an increasing discussion regarding the relative effects of load carriage design on comfort and how equipment affects the mobility of police (Dempsey et al., 2013; Filtness et al., 2014; Holmes, McKinnon, Dickerson, & Callaghan, 2013; Ramstrand et al., 2016).

In addition to the load carriage, the long periods of sitting in fleet vehicles have been identified as contributing to musculoskeletal disorders in the police (Gyi & Porter, 1998). It is, however, unclear how this could be affected by altering the load carriage system used by the police.

Work stress related to organisational and social context factors are also risk factors associated with the development of musculoskeletal disorders (da Costa & Vieira, 2010). The police are an occupational group known to have a high level of occupational stress (Berg, Hem, Lau, & Ekeberg, 2006). Despite this, very little is known about the association between psychosocial workplace factors and musculoskeletal disorders among this group.

Within the context of this thesis, musculoskeletal pain is considered to be an initial signal or symptom of musculoskeletal disorders. As such, self-reported pain was used as a primary outcome measure. Although it is well known that self-reported musculoskeletal pain does not reveal the actual cause of the problem, this measure can still be used to represent an experience of having a disorder in the musculoskeletal system. Musculoskeletal pain cannot always be explained by a pathophysiological mechanism and, therefore, both physical and psychological factors must be considered when trying to understand the experience of pain (Toomingas, Mathiassen, & Tornqvist, 2012).

In this thesis, two studies have been conducted to determine the prevalence of musculoskeletal pain among the Swedish police and to explore the potential association between physical and psychosocial workplace factors and musculoskeletal pain. An additional two studies have been conducted to explore the biomechanical effects of wearing mandatory police equipment during common work situations. It is anticipated that this thesis will focus attention on the work environment of the Swedish police and thus provide evidence to guide the development of ergonomic interventions which reduce the prevalence of musculoskeletal disorders in this population. It is further anticipated that the findings of this thesis will provide evidence to assist the police authorities in determining workplace interventions and policy.
amendments that should be prioritised to reduce the prevalence of musculoskeletal disorders.
Background

Police

The Swedish police force employs approximately 28500 individuals, of which 20000 are police officers and the remaining 8500 are civil servants (Polisen, 2015). The Swedish national police force is answerable to the government and is led by the National Police Commissioner. The mission of the police force is described in the Police Act (SFS 1984:387) and has the overall aim of reducing crime and increasing public safety. Prior to 2015, the Swedish Police Authority was administratively divided into 21 regions. On January 1, 2015 the Swedish Police Authority went through a process of reorganisation, which resulted in an aggregation of police regions from 21 to 7. This organisational change is not mirrored in this thesis as all data collection was conducted before 2015.

During the period when the data collection for this thesis took place, the Swedish Police Authority had approximately 7300 employees working on active duty. The police officers of specific interest in the two biomechanical studies were those commonly termed uniformed police who work in active duty. Other groups of police working in active duty include dog handlers, traffic police, marine police, local police and mounted police. Uniformed police perform patrol duties, which include emergency calls, crime investigations and crime prevention at a local level and represent the largest group working in active duty (Svedberg & Alexanderson, 2012). In the two studies, based on the survey data included in this thesis, all categories of police working in active duty were included, with the overall majority representing uniformed police. Although there are differences in work tasks between these categories of police they are all required to wear mandatory equipment during working hours.

Work environment of the police

The work environment of uniformed police is characterised by several specific occupational exposures. These exposures can be physical, psychological and
psychosocial in nature, and it is likely that they are also experienced by individuals representing other emergency service occupations. The physical work environment of police is characterised by sitting for long periods of time in fleet vehicles (McKinnon, Callaghan, & Dickerson, 2011), shift work, physical confrontations and carrying loads (i.e. mandatory equipment such as duty belt and body armour). Besides standing and walking, uniformed police are required to be able to run, climb stairs, balance, jump and lift heavy objects or people (Anderson, Plecas, & Segger, 2001). Despite the common perception that police work involves a high level of physical activity it has previously been demonstrated that the majority of their work is sedentary (Ramey et al., 2014). A certain degree of fitness is, however, necessary to meet the various unpredictable aspects of police work.

It is accepted that physical exercise has beneficial effects on musculoskeletal pain (Andersen et al., 2010; Hayden, Van Tulder, Malmivaara, & Koes, 2005), and it has previously been demonstrated that police with a high level of physical fitness are less likely to experience sprains, back pain and chronic pain (Nabeel, Baker, McGrail, & Flottemesch, 2007). Physical exercise among Swedish police is generally performed during the police officers’ leisure time (Elgmark, Bæk Larsen, Tranberg, & Ramstrand, 2013). During working hours, Swedish police working in active duty are permitted one hour of physical exercise per week, given that the circumstances allow it. There are no mandatory physical fitness tests required after graduating from the police academy. Being physically prepared for work therefore becomes the individual’s responsibility. This imposes a risk that police officers are not fit for their specific work exposures.

Besides the physical exposures to which police are subject, it is well recognised that police work also includes an element of stress. Work stress is known to be related to musculoskeletal disorders and it has been suggested that muscle tension as a result of psychosocial work factors could be a potential pathway between work stress and musculoskeletal disorders (Carayon, Smith, & Haims, 1999; Theorell, Harms-Ringdahl, Ahlberg-Hulten, & Westin, 1991). Stress in police work is typically divided into two distinct categories (He, Zhao, & Archbold, 2002; Kop, Euwema, & Schaufeli, 1999; Maguen et al., 2009), namely psychological stressors associated with the nature of police work and psychosocial stressors related to the organisation of work and workplace culture. Psychological stressors related to the nature
of police work include factors such as threats, violence, exposure to dangerous situations, traumatic incidents, unpredictable incidents, gruesome crime scenes, violent arrests and appearing in court (He et al., 2002; Kop et al., 1999). Psychosocial stressors of police work are more generic in nature and include management style, lack of support, poor communication, inadequate resources and time pressure (Biggam, Power, Macdonald, Carcary, & Moodie, 1997; Kop et al., 1999). Both types of stressors in police work have been associated with outcomes such as sickness absence and psychological distress (Liberman et al., 2002; Svedberg & Alexanderson, 2012). The association between work stress and musculoskeletal disorders in police has, however, not previously been investigated. In this thesis, the focus has been on physical and psychosocial exposures in the work environment of the Swedish police and, therefore, the stressors associated with the nature of police work such as threats and violence are not included.

**Musculoskeletal disorders and pain**

Musculoskeletal disorders are a major health problem in most parts of the world (Farioli et al., 2014; Punnett & Wegman, 2004; Vos et al., 2017) and, as described earlier, also one of the most frequently reported work-related disorders among the Swedish police (Arbetsmiljöverket, 2009, 2016b). In Sweden, about one-third of the working population experiences some kind of musculoskeletal pain in the back, neck, shoulders, arms or lower extremities at least one day per week (Arbetsmiljöverket, 2016a). The prevalence of musculoskeletal disorders is higher among women than men and prevalence increases with age for both males and females (Arbetsmiljöverket, 2014).

Musculoskeletal disorders are defined as disorders and/or injuries that affect muscles, tendons, the skeleton, cartilage, ligaments and nerves (Luttmann, Jäger, Griefahn, Caffier, & Liebers, 2003; Punnett, 2014). Disorders can range in severity and result in short-term, episodic or chronic manifestations. Musculoskeletal disorders are recognised by the World Health Organisation (WHO) to be work-related when the performance of work and the work environment significantly contribute to, or exacerbate, their development (WHO, 1985). Work-related musculoskeletal disorders are multifactorial, suggesting that work organisation, physical, psychosocial and individual
factors can, independently or in combination, lead to the development of a musculoskeletal disorder (Bernard & Putz-Anderson, 1997). This definition differs from the term “occupational disease” in which a direct cause-effect relationship between work exposure and disease can be detected (i.e. asbestosis of coal miners) (Armstrong et al., 1993; Punnett, 2014).

Pain is the most common symptom of musculoskeletal disorders and is defined by the International Association for the Study of Pain (IASP) as “an unpleasant sensory or emotional experience associated with actual or potential tissue damage, or described in terms of such damage” (IASP). The experience of pain is always subjective and linked to one or more parts of the body. It is, however, important to recognise that the experience of pain can exist without any tissue damage or other pathophysiological cause (Toomingsas et al., 2012). This kind of pain is usually psychological in nature, which implies that the experience of pain is complex and might represent something other than actual tissue damage. Most studies investigating pain are based upon self-reported measures. While musculoskeletal pain is typically reported as frequency and intensity of pain in a specific region of the body, recent studies have begun to investigate the implications of experiencing pain in more than one region simultaneously. Multi-site musculoskeletal pain is defined as pain in two or more body regions at the same time and has been found to be more frequently reported than single-site musculoskeletal pain (Kamaleri, Natvig, Ihlebaek, & Bruusgaard, 2008; Miranda et al., 2010; S. Neupane, Miranda, Virtanen, Siukola, & Nygard, 2011). The consequences of multi-site pain are more debilitating and have a greater association to limited work ability and sickness absence than single-site musculoskeletal pain (Haukka et al., 2013; Miranda et al., 2010; Morken et al., 2003; Natvig, Eriksen, & Bruusgaard, 2002).

**Development of musculoskeletal disorders**

As previously described, factors contributing to the development of musculoskeletal disorders can be divided into non-work-related and work-related factors. The non-work-related risk factors include individual factors, activities undertaken during leisure time and lifestyle factors, whereas the work-related factors include both physical and psychosocial aspects of work.
Given that the focus of this thesis is work-related factors, this section will review factors specific to the workplace that have been identified as affecting the development of musculoskeletal disorders.

Physical risk factors include heavy lifting, prolonged standing, working with arms above shoulder height, repetitive motion patterns, whole-body or segmental vibration, squatting/kneeling and static muscular load (Andersen, Fallentin, Thorsen, & Holtermann, 2016; Sterud & Tynes, 2013). Disorders and injuries occur when the load-bearing capacity of the musculoskeletal system is subjected to an external mechanical load which is beyond the capacity of the system (Luttmann et al., 2003). The injury mechanism is dependent on the type of load applied to the tissue. A high load exceeding the tolerance level of the tissue applied on one occasion can be enough to cause a musculoskeletal injury. At the same time, relatively low levels of load applied over a long period of time can accumulate into an injury as the tissue tolerance level decreases due to repeated micro trauma or insufficient recovery (McGill, 1997).

Psychosocial factors influencing work-related musculoskeletal disorders include organisational and social context factors such as high demands and low control of one’s own work activities as well as social support from co-workers and supervisors (Carayon et al., 1999). The high prevalence of work-related musculoskeletal disorders has been found to be associated with psychosocial risk factors in the work environment in a number of occupational groups, including nurses and other health sector employees (Amin, Nordin, Fatt, Noah, & Oxley, 2014; Bernal et al., 2015; S. Neupane, Nygard, & Oakman, 2016), dentists (K. Cho, Cho, & Han, 2016; Feng, Liang, Wang, Andersen, & Szeto, 2014; Sakzewski & Naser-ud-Din, 2015), miners, construction workers and teachers (Ekpenyong & Inyang, 2014; Yue, Xu, Li, & Wang, 2014). This relationship has, however, not been investigated among police.
Policies and guidelines regulating the work environment

In 1950 the World Health Organisation (WHO) and the International Labour Organisation (ILO) recognised the work environment as an important global issue and initiated a collaboration to develop documents, strategies and policies to protect the health, safety and wellbeing of workers (J. Burton, 2010). While the initial focus of health and safety work was directed toward aspects of the physical work environment, a shift to include psychosocial factors has evolved during the past few decades. In 2010, the WHO developed a global framework as guidance for the development of healthy workplaces. A healthy workplace, as defined by the WHO, is one where employees and employer collaborate in a continual improvement process of protecting and improving the health, safety and wellbeing of workers and to create a sustainable workplace. Included in this definition is the concept that continual improvement processes should take into account the physical and psychosocial work environment, together with personal health resources in the workplace (J. Burton, 2010).

In Sweden, health and safety work in the workplace is regulated by the Work Environment Act (SFS 1977:1160) which encompasses technical, physical, organisational, social and work content factors. To highlight the importance of the psychosocial aspects of work life, a new provision regarding organisational and social work environment (AFS 2015:4) came into effect in 2016. Use of continual improvement process as a means of work environment management is also regulated in a provision (AFS 2001:1), which states that the employer and employee are both responsible for investigating, carrying out and following up on activities to prevent ill-health and accidents at work.
Theoretical framework

In this thesis, increasing the knowledge of factors related to the development of musculoskeletal disorders among police was the main objective. A theoretical framework including two models was applied to describe the potential relationships between exposures in the work environment and the development of musculoskeletal disorders in this thesis.

A conceptual model presenting the influence that workplace factors may have on the development of musculoskeletal disorders was adapted from the U.S. National Research Council (NRC) (National Research Council, 2001). The overall structure of the model presents potential factors in the workplace and physiological pathways within the person that can, independently or in combination, lead to development of musculoskeletal disorders, see Figure 1.

Within this thesis, this model was used to guide the selection of independent and dependent variables included with each of the studies. Factors related to the person were selected to serve as dependent variables. Pain was investigated as the dependent variable in Studies I and II while biomechanical factors were investigated as the dependent variable in Studies III and IV. Specific workplace factors served as the independent variables within each study. Mandatory equipment borne by the police and time spent sitting in fleet vehicles are physical exposures which, in this thesis, were defined as external loads. These workplace factors were the main independent variables in Studies I, III and IV. Organisational and social context factors contributing to musculoskeletal disorders were managed using the job demand control (JDC) model in combination with a variable representing social support from co-workers and supervisors. These served as the independent variables in Study II.
Workplace factors described in the NRC model comprise external physical loads associated with job performance, organisational factors and social context factors. The external loads to which a person is subject at work are transmitted through biomechanical forces, which subsequently create internal loads on tissues and other anatomical structures. Biomechanical loading, exceeding the internal tolerance or the ability of the structures to withstand the load, leads to tissue damage. The result of an excessive external load can be pain, discomfort, impairment or disability. The relationship between external loading conditions and the biomechanical response in the body is typically investigated within research disciplines such as physiology and biomechanics.
Organisational and social context factors have a more indirect effect on the occurrence of musculoskeletal disorders. Organisational factors include issues such as management structure, level of autonomy when performing a task, work pace, exposure to specific work tasks and the use of ergonomic principles to balance work demands and personal capacity. An example of this could be the possibility to rotate between work tasks to prevent unilateral exposure of the body. Interpersonal relationships in the workplace and social support from co-workers, supervisors and others are examples of social context factors. These factors play an important role for the psychosocial health of the individual and have a buffering effect against psychological stressors (Karazek & Theorell, 1990). Exposure to psychological stress can result in musculoskeletal disorders such as muscle tension in the upper back or neck. Epidemiology plays a central role in increasing understanding of what causes or sustains diseases in populations (Bhopal, 2016). The search for associations between exposure and outcomes is therefore useful in the context of explaining the occurrence of musculoskeletal disorders.

How a person copes with various exposures in the workplace is highly individual. Individual factors which should be considered from a whole-person perspective when investigating the occurrence of musculoskeletal disorders include age, gender, body mass index, living habits, physical exercise, self-efficacy, etc. Moreover, it includes the individual’s response to pain, coping mechanisms, social support systems at home and in the workplace, and the ability to adjust to the context of work are important factors. As specific workplace factors and musculoskeletal disorders were the main focus of this thesis, the individual factors as described above were not investigated to such an extent as could be desired.

The NRC model describes numerous potential pathways to the development of musculoskeletal disorders with exposure coming from different factors in the workplace. It is important to recognise that one potential pathway does not exclude another and that the model is intended to describe the problems of musculoskeletal disorders from different perspectives.

Organisational and social context factors in the workplace are essential parts of the psychosocial work environment and have previously been found to be associated with musculoskeletal disorders (da Costa & Vieira, 2010; Punnett & Wegman, 2004). These factors can be further conceptualised using Karasek’s Job Demand Control (JDC) model, which is one of the most
commonly used models to describe work stress, see Figure 2. The model aims to explain the relationship between work and health from the two dimensions, job demands and job control (Robert Karasek, 1979). The model suggests that the combination of high job demands and low job control (high strain hypothesis) would introduce the highest risk for reduced health and well-being. Jobs with high demands and high control are, on the contrary, more likely to result in a positive psychosocial outcome, where the individual has greater possibility of learning and self-development (Robert Karasek & Theorell, 1992). Social support is a third dimension added later to the model to expand the relationship between work and health and to include a social dimension in the work environment (Johnson & Hall, 1988). Social support is suggested to have a buffering effect between psychological stressors in the workplace and various health outcomes (Robert Karasek & Theorell, 1992). The JDC model has previously been used in studies investigating musculoskeletal disorders and multi-site musculoskeletal pain (Herin, Vézina, Thaon, Soulart, & Paris, 2014; Subas Neupane, Pensola, Haukka, Ojajärvi, & Leino-Arjas, 2016; Sembajwe et al., 2013; Sommer, Frost, & Svendsen, 2015).

Figure 2. The Job Demand Control model by Karasek 1979
Rationale

Musculoskeletal discomfort and musculoskeletal pain are the two most common measures of musculoskeletal disorders reported among police (Donnelly, Callaghan, & Durkin, 2009; Filtness et al., 2014; Gyi & Porter, 1998; Nabeel et al., 2007; Ramstrand et al., 2016). Measures of musculoskeletal discomfort and pain are typically collected using self-reporting questionnaires. To date, these variables have not been investigated in large sample studies for police working in active duty. Musculoskeletal pain in police has only ever been investigated by exploring pain experienced in single regions of the body. Over the past decade, it has been determined that multi-site musculoskeletal pain, i.e. pain in more than one region, is more debilitating than single-site pain and, as such, may be a more relevant variable to explore (S. Neupane et al., 2011; Scudds & Robertson, 2000; Sembajwe et al., 2013). Multi-site musculoskeletal pain among the police has not previously been investigated. It is commonly accepted that factors contributing to musculoskeletal disorders can have both physical and psychosocial manifestations. Associations between subjective health complaints, job pressure and low support have previously been reported in the Norwegian police (Berg et al., 2006). However, the association between psychosocial work place factors and multi-site musculoskeletal pain within this occupational group has not previously been explored.

Musculoskeletal disorders among the police have primarily been investigated by exploring the biomechanical implications of wearing standard load carriage (duty belt and body armour) during walking (Ramstrand et al., 2016) and driving fleet vehicles (K. M. Gruevski, M. W. Holmes, C. E. Gooyers, C. R. Dickerson, & J. P. Callaghan, 2016; Holmes et al., 2013). The police themselves perceive the duty belt to be a source of discomfort and a potential cause of low back pain (Brown et al., 1998; Holmes et al., 2013; Ramstrand & Larsen, 2012) suggesting that it may be relevant to explore alternative means of load carriage. To date, the redistribution of loads typically carried in the duty belt onto a load-bearing vest has been investigated in terms of self-reported discomfort and gait kinematics (Filtness et al., 2014; Ramstrand et al., 2016). Ramstrand et al. are the only group who incorporated an alternate load carriage system, in this case a thigh holster, in their study design. Gait kinetics have not previously been explored in relation to alternative load
carriage designs among the police. Potential changes in gait kinetics could be of interest when evaluating the effect of an alternate load carriage design, as the load from the duty belt is redistributed to a thigh holster and a load-bearing vest.

The studies in this thesis will contribute to the current body of knowledge with new insights into musculoskeletal disorders among Swedish police working in active duty. Musculoskeletal disorders were explored in terms of the prevalence of musculoskeletal pain in specific body regions as well as multi-site musculoskeletal pain. As suggested by the NRC model, both physical and psychosocial exposures in the workplace have the potential to influence the occurrence of musculoskeletal disorders. Physical exposures of specific interest in this thesis were related to mandatory police equipment and fleet vehicles whereas psychosocial exposures were managed using the JDC model and an index representing social support. The extent to which these workplace exposures are associated with multi-site musculoskeletal pain among police were explored and can serve as an additional component in quality improvement work concerning the work environment of the police, both nationally and internationally. By exploring the biomechanical effects of an alternate load carriage design incorporating a load-bearing vest and thigh holster, police authorities will be provided with evidence to facilitate the development of new load carriage system and information to guide policy regarding the use of mandatory equipment.
Aim

The overall aim of this thesis was to increase knowledge about musculoskeletal disorders in the Swedish police by investigating the prevalence of pain and the relationship to physical and psychosocial factors in the work environment.

Specific aims of each study:

Study I
To document the prevalence of multi-site musculoskeletal pain among Swedish police and to explore the association between discomfort experienced from mandatory equipment, prolonged sitting in fleet vehicles and multi-site musculoskeletal pain.

Study II
To explore the association between psychosocial work environment, as defined by the JDC model, and multi-site musculoskeletal pain among Swedish police.

Study III
To investigate gait kinematics and kinetics in active duty police fitted with an alternate load carriage design incorporating a thigh holster in comparison to standard police load carriage incorporating a belt mounted hip holster.

Study IV
To explore the relative effects of different load carriage designs on perceived discomfort and body-seat interface pressures in police when driving.
Methods and material

Design

In this thesis, four quantitative studies addressing different elements of the NRC model have been carried out, see Figure 3. The studies have descriptive, cross-sectional and experimental designs with different methods of data collection. A descriptive and cross-sectional design was chosen for Studies I and II, as a means of investigating the prevalence of musculoskeletal pain and to explore possible associations between musculoskeletal pain and discomfort experienced from wearing mandatory equipment, sitting in fleet vehicles and the psychosocial work environment. The study design allowed for inferences to be made about the study population at a specific point in time (Kirkwood & Sterne, 2010). Studies III and IV utilised an experimental study design by applying biomechanical measures to explore the use of mandatory equipment (duty belt and body armour) while walking (Study III) and driving police fleet vehicles (Study IV). To complement the biomechanical measures, a questionnaire of self-reported discomfort was included in Study IV. The intention of Studies III and IV was to investigate the effect of different load carriage designs while controlling for factors which would otherwise influence the outcome (Creswell, 2013). An overview of the different study designs is presented in Table 1.

Table 1. Overview of the four studies included in this thesis.

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Sample</th>
<th>Data collection</th>
<th>Data analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Survey, Descriptive and Cross-sectional Quantitative</td>
<td>4185 police working in active duty</td>
<td>Self-report questionnaire</td>
<td>Descriptive statistics and binomial logistic regression</td>
</tr>
<tr>
<td>II</td>
<td>Survey, Cross-sectional Quantitative</td>
<td>4185 police working in active duty</td>
<td>Self-report questionnaire</td>
<td>Binomial logistic regression</td>
</tr>
<tr>
<td>III</td>
<td>Experimental Quantitative</td>
<td>20 active duty police from middle-sized municipality</td>
<td>3D instrumented gait analysis</td>
<td>Friedman Two-Way ANOVA and post hoc test</td>
</tr>
<tr>
<td>IV</td>
<td>Experimental Quantitative</td>
<td>22 active duty police from middle-sized municipality</td>
<td>Self-reported questionnaire and pressure mapping</td>
<td>Wilcoxon signed-rank test</td>
</tr>
</tbody>
</table>
The relationship between the four studies in this thesis and different elements of the NRC model is presented in Figure 3. Bold arrows going between workplace factors and the person represent the relationship between exposure and outcome variables studied in this thesis. Organisational and social factors are combined in the use of the JDC model in combination with a variable representing social support. Internal tolerance of the musculoskeletal system is not addressed in any of the studies.

Figure 3. Elements of the NRC model which have been addressed in this thesis.
Participants

All participants included in Studies I – IV were police officers working in active duty. The unpredictable nature of police work induces an increased risk of violence and physical confrontations. To meet these risks of police work uniformed police wear duty belts (containing OC spray, handcuffs, torch, baton, radio, weapon and extra ammunition) together with protective body armour as a part of their uniform at all times while on duty. As the location of work is constantly changing, the police fleet vehicle serves a means of transportation, a mobile office, and storage for extra equipment. Working as part of the uniformed police force therefore results in sitting in fleet vehicles for a large proportion of the work shift.

Recruitment of participants for all four studies was conducted though a contact within the Swedish Police Authority. The contact was specifically employed to work with issues related to the work environment and occupational health and safety of the Swedish police. Close collaboration with the Swedish police was a prerequisite for recruitment as Studies I and II required access to the work e-mail address of participants and Studies III and IV required participants to be tested in full police uniform as well as access to police fleet vehicles.

Inclusion criteria for Studies I and II were that participants should hold a position as a police officer working on active duty within the Swedish police. The inclusion criteria for Studies III and IV were uniformed police officers working on active duty without any musculoskeletal pain/disorders affecting their ability to performed police work at the time of data collection. An equal representation of genders was requested for Studies III and IV. An overview of the participants in the four studies is presented in Table 2.
Table 2. Participants in Studies I – IV

<table>
<thead>
<tr>
<th>Study</th>
<th>Total N</th>
<th>Mean age (range)</th>
<th>Sex (female)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>4185</td>
<td>30-34* (20 - 50+)</td>
<td>25.7%</td>
</tr>
<tr>
<td>II</td>
<td>4185</td>
<td>30-34* (20 - 50+)</td>
<td>25.7%</td>
</tr>
<tr>
<td>III</td>
<td>20</td>
<td>34.5 (24 - 61)</td>
<td>55%</td>
</tr>
<tr>
<td>IV</td>
<td>22</td>
<td>30.0 (26 - 41)</td>
<td>50%</td>
</tr>
</tbody>
</table>

* Age in Studies I and II were measured in intervals of 5 years.

Instruments and data collection

Data collection for the four studies included in this thesis took place in the period 2012 – 2014. Three data collections were carried out. Studies I and II were based on the same data collection.

Study I and II

Data collection for Studies I and II was carried out using a survey containing questions about the physical and psychosocial work environment. The survey was based on questions from the Swedish Work Environment Survey (SWES) (Arbetsmiljöverket, 2014) and permission to use the questions was granted by Statistics Sweden. The SWES was introduced in 1989 and, since this time, has been applied biannually to a sample of the Swedish working population. After each wave of data collection, Statistics Sweden has presented the SWES results stratified for professions, gender, age, level of income and educational level. This structure allows for comparison over time and between groups. For Studies I and II, additional questions were developed and added to the SWES survey by the research team and in collaboration with a physiotherapist employed by the Swedish National Police and a police officer who holds a position as an occupational health and safety representative. Additional questions aimed to collect data specifically related to the police, including demographics, discomfort experienced from mandatory equipment (duty belt...
and body armour), work schedule, exercise habits and time spent in fleet vehicles.

Prior to the distribution of the survey, a group of representative police officers participated in pilot testing. The pilot testing of the survey questions was conducted to check face validity. After answering the pilot survey, two focus-group sessions were conducted with one group (n = 5) representing a larger city and a second (n = 4) representing a smaller town. During the sessions, the police officers were requested to express their opinions about the questions included in the survey. For the purpose of clarification, several modifications were made to questions developed by the research team and some questions were removed because of lack of relevance. The final survey consisted of 146 questions.

Data collection was carried out between February and March 2013 using an online self-administered survey sent out to the participants via their work e-mail address. To maximise the response rate, personalised reminders were sent out after 2 and 4 weeks (Sánchez-Fernández, Muñoz-Leiva, Montoro-Ríos, & Ibáñez-Zapata, 2010). As it was not possible to identify only those police who worked as active duty officers, the survey was distributed to all personnel (approximately 28000) working within the Swedish police force. Only those working as active duty officers were requested to answer. A control question was included in the survey to ensure each participant’s position as an active duty officer. The estimated number of active duty police officers employed by the Swedish Police at the time of data collection was 7387, of which 4185 responded. The overall response rate was 56.7%, varying across the 21 regions within which the Swedish police force was divided at the time of the study.

Study III

Data collection was conducted in the biomechanics laboratory at Jönköping University during spring 2012. A biomechanical analysis was performed on each participant (n=20) using a three-dimensional gait analysis system (Qualisys AB, Gothenburg) consisting of eight cameras and two force plates embedded in the floor of the laboratory (Advanced Mechanical Technologies Inc., Watertown, MA, USA). Reflective markers were placed on predetermined body locations in order to define segments and major joints. A
total of 38 reflective markers were placed on each participant’s body, based on the principle of the cluster marker model proposed by Cappozzo et al. (1997). Two modifications to the Cappozzo model were made as the duty belt and thigh holster covered landmarks on the pelvis and right thigh where reflective makers are normally placed. Tracking makers for the pelvis were replaced with a posteriorly placed U-shaped cluster which included three reflective makers (see figure 4) while the rigid cluster normally placed on the right thigh was replaced with three reflective makers on the anterior aspect of the thigh (see figure 5). The static trail was captured without the duty belt which allowed for the reflective markers on the left and right anterior superior iliac spine (ASIS) and sacrum to be placed together with the U-shaped cluster. After the static file was captured the ASIS markers and the marker on the sacrum were removed and the belt was placed around the waist being careful not to disturb the position of the U-shaped cluster.

Figure 4. Cluster with three reflective makers placed on the sacrum in the standard load carriage condition.

Marker placement was conducted by the same person for all measurements in order to maximise reliability. Force plates and cameras were calibrated before each measurement. Participants walked for 5 minutes on a treadmill to familiarise themselves with the set-up before each new testing condition. A standing calibration file was collected for each participant. Each participant was tested under three conditions wearing: a) standard load carriage (duty belt and body armour), b) an alternate load carriage (load-bearing vest, thigh holster and body armour), and c) a control condition without any equipment,
see Figure 5. The order of testing was randomised, and each participant walked at a self-selected speed. Five walking sequences were captured for each individual under each load carriage condition.

![Figure 5](image)

Figure 5. The three conditions tested in study III. From left to right; standard load carriage, alternate load carriage and control condition.

**Study IV**

Discomfort related to the vehicle seat was assessed using the Automobile Seating Discomfort Questionnaire (ASDQ) (Smith, Andrews, & Wawrow, 2006) together with questions related to police-specific tasks and equipment developed by Donnelly et al. (2009). Discomfort ratings in specific body regions were assessed by questions previously validated by Mergl et al. (2005). All questions were rated on a scale ranging from 0 mm (no discomfort) to 100 mm (extreme discomfort). All questionnaires were translated to Swedish and back-translated to English to ensure linguistic validity (WHO, 2010).

Pressure between the body of the participant and seat pan and backrest of the driver seat were measured using a pressure measuring system COMFORMat
model 5330 (Tekscan, Boston, USA). Pressure mats for both the seat pan and backrest had the dimensions of 47.1 x 47.1 cm and included 1024 sensor cells, each covering an area of 2.14 cm². The sensor cells were distributed in a matrix of 32 rows and 32 columns for each pressure mat. The pressure mats were equilibrated following the manufacturer’s instructions prior to testing. Mats were attached to the seat pan and backrest of fleet vehicles using tape and not removed between trials.

Data collection was conducted in a middle-sized county, in Sweden, between February and March of 2014. Police officers were tested under three different conditions while driving a standard police vehicle (Volvo V70) and wearing two different configurations of load carriage designs: a) standard load carriage (duty belt and body armour), b) alternate load carriage (load-bearing vest, thigh holster and body armour), and c) a control condition without any equipment, see figure 6. The order of the testing was randomised. Participants were informed about the possibility to make personalised adjustments to the positions of the seat pan, backrest and steering wheel before data collection was initiated. Each trial was conducted while driving a standardised route of 22 km, with a mixture of city driving and the suburban driving. Driving sessions lasted between 25-30 minutes. After each of the driving sessions, participants were requested to answer the discomfort questionnaires.
Figure 6. The three conditions tested in study IV. From left to right; standard load carriage, alternate load carriage and control condition.

Variables of main interest

Studies I and II

Multi-site musculoskeletal pain was the main outcome variable in both Studies I and II. Musculoskeletal pain was measured separately for the following four body regions: upper back or neck; lower back; shoulders or arms and hips; knees or feet. Musculoskeletal pain was assessed by separate items phrased as: “During the last three months have you, after work, experienced pain in [body region] …?” Response alternatives were measured on a 5-point scale and each item was dichotomised into 1 = one day per week or more and 0 = not at all/seldom or a few days per month. This level of dichotomisation was chosen as it corresponds to the cut-off level used by Statistics Sweden in the biannual SWES reports. Multi-site musculoskeletal was defined as pain in two or more body regions at the same time (Carnes et al., 2007; Solidaki et al., 2010).
The main exposure variables in Study I were discomfort experienced from wearing the duty belt and body armour and time spent sitting in fleet vehicles. Discomfort experienced from wearing the duty belt and body armour were measured separately and included experiencing discomfort both while standing/walking and sitting. Discomfort was coded as a dichotomous variable with no discomfort being the reference category. Time spent sitting in fleet vehicles was measured as an estimation of percentage of an average working shift spent sitting in fleet vehicles either driving or in the passenger seat. Time spent sitting in fleet vehicles was measured on a response scale with five intervals from ranging from 0% to 75% of the time or over. The variable was coded as a dummy variable and added to the model, with the lowest category being the reference.

In Study II, two different regression analyses were performed. In the first analysis, job demands, job control and social support were the main exposure variables. The indices for job demands and job control were generated using four items from the SWES for each variable. The items included in the indices have previously been defined by the Swedish Work Environment Authority (SWEA) in publications on work environment in Sweden in general (Arbetsmiljöverket, 2014). Items included in the job demand index were related to: working overtime, restricted possibilities to take breaks, stressful working conditions, attention- and concentration-demanding work and the overall feeling of having too much to do at work. The index for job demand was based on items related to: possibility to influence work in terms of planning, methods or pace, order of one’s own work, and the overall feeling of being able to influence one’s own work. For both indices, items were dichotomised following the description of the SWEA and summed into a new variable. The indices ranged from 0 to 4 and scores <2 were categorised as low demands/control and high demands/control as ≥2. Low demands and high control respectively served as the reference categories in the regression model. An index representing social support from co-workers and supervisors was based on six items from the SWES previously used in a publication based on the same dataset (Andersson, Larsen, & Ramstrand, 2017). The six items were related to: supervisors or co-workers expressing support or encouragement when work is problematic, supervisors or co-workers expressing appreciation for the work performed and advice or help when working with difficult tasks. Each item was dichotomised and summed into a new variable ranging from 0
to 6. Scores of $< 3$ were categorised as low support and $\geq 3$ as high support. Low support was used as the reference category in the regression model.

In the second regression analysis performed in Study II, the four job categories based on Karasek’s JDC model and the index for social support were the main exposure variables. The four job categories included: low-strain jobs (low demands, high control); passive jobs (low demands, low control); active jobs (high demands, high control); and high-strain jobs (high demands, low control). When added to the regression model, low-strain jobs served as the reference category. Social support in the second analysis was identical to that of the first regression analysis in Study II.

Age, sex, physical workload factors and physical exercise were considered as potential confounders in both Studies I and II. Additionally, psychosocial variables were controlled for in Study I and tobacco use was controlled for in Study II. These variables have previously been found to be related to multi-site musculoskeletal pain and could also be considered to be associated with physical and psychosocial work environment (Herin et al., 2014; Solidaki et al., 2010; Sommer et al., 2015).

**Study III and IV**

The main outcome measures in Studies II and IV are related to the biomechanical loading of the body when exposed to external load from the work environment. In Study III, the main dependent variables were temporospatial parameters together with gait kinematics and kinetics in the frontal, transversal and sagittal planes. Kinematic data had a special focus on variables related to the pelvic region, lower trunk and hip joints. Temporospatial parameters extracted from the data were cycle time (steps/s), velocity (m/s), stride length (m) and stride width (m). Kinematic variables of interest for this study were: angular range of motion (ROM) in the sagittal, frontal and transversal plane for the trunk, pelvis, hips, knees and ankles. Kinetic variables included were moments (Nm/BW) and powers (W/BW) for the hips, knees and ankles in the sagittal and frontal plane. Kinematic variables were reported for stance phase and swing phase separately whereas kinetics was only reported for the stance phase.
Ratings of discomfort, contact pressure and contact area were the main dependent variables in Study IV. Items of discomfort related to the vehicle seat, operational task performed in the vehicle and specific body regions were measured using a visual analogue scale of 100 mm. Contact area (mm$^2$) was defined as the area of loaded sensor cells within a predefined area. Contact pressure (mmHg) was defined as the force applied to the sensor cells divided by the contact pressure.

The independent variables in Studies III and IV were the three conditions of standard load carriage condition, alternate load carriage condition, and control condition. These conditions are described under the heading Instruments and Data Collection above.

Data analysis

Study I

The prevalence of musculoskeletal pain was presented for four body regions: upper back or neck, lower back, shoulders or arms and hips, knees or feet. Frequencies and percentages were calculated for all variables for the total study population, as well as stratified by no pain or single site-pain and multi-site pain.

Binomial logistic regression was performed to ascertain the effects of exposure variables and confounders on multi-site musculoskeletal pain. Odds ratios were calculated as a measure of association. To meet the assumptions of binomial logistic regression, tests of multicollinearity between the independent variables and outliers in the sample were performed. No multicollinearity was found but 20 outliers were removed due to studentised residuals exceeding 2.5 standard deviations. The regression analysis was performed in three steps, with the first step including the exposure variables of specific interest to the aim of the study, in the second step physical and psychosocial workload factors were added to the model, and, in the third step, the model was controlled for physical exercise, age and sex.
Study II

Descriptive statistics presenting the frequency and percentage were calculated for all variables included in the analysis and stratified into no pain or single-site pain and multi-site pain.

Two binomial logistic regression analyses were performed to estimate the degree of association between job stress and multi-site musculoskeletal pain. The first analysis aimed to explore the association between job demand, job control, social support and multi-site musculoskeletal pain. The second analysis aimed to explore the association between the four categories of the JDC model (low strain, passive, active and high strain), social support and multi-site musculoskeletal pain. Tests for the assumption of binomial logistic regression were conducted by investigating multicollinearity between the independent variables and testing for outliers in the sample. No violations of assumption were found. In both analyses, exposure variables and confounders were inserted into the regression model in three steps. The crude odds ratios of variables related to job stress were derived in the first step, support from co-workers and supervisors was added in the second step, and, in the third step, the model was adjusted for potential confounders age, sex, physical workload factors, physical exercise and tobacco use.

Study III

Kinematic data was filtered using a fourth-order zero-lag Butterworth low-pass-filter, with a cut-off frequency of 15 Hz. Ground reaction force data were filtered with a cut-off frequency at 20 Hz (moments) and 30 Hz (powers). Visual 3D™ software (C-Motions, Inc. Germantown, USA) was used to calculate temporospatial parameters, kinematic and kinetic variables. Bodyweight was adjusted to account for the weight of load carriage for relevant trials. One trial for each condition was then randomly selected to represent the conditions in the statistical analysis.

Comparisons between load carriage conditions for temporospatial, kinematic and kinetic data were conducted using a Friedman test for non-parametric related samples. When a significant difference was found, pairwise comparisons were performed (IBM SPSS statistics 21). To accommodate for multiple comparisons, Bonferroni adjustment of the P value resulted in a significance level of P < 0.017.
Study IV

Ratings of discomfort in the control condition served as a baseline and were subtracted from the discomfort ratings of the two load carriage conditions. Only those items from the questionnaires with discomfort ratings greater than 10 mm for at least one of the conditions were chosen for further analysis. A Wilcoxon signed-rank test was used to determine if there was a significant difference in median values of discomfort between the standard and alternate load carriage conditions. An alpha level at $P < 0.05$ was set to determine statistical difference.

Pressure data from the backrest of the fleet vehicle were divided into two areas representing the upper back (16 rows and 32 columns) and lower back (15 rows and 32 columns). The data from the seat pan was divided into four areas representing the left buttock, right buttock (15 rows and 16 columns) and left thigh, right thigh (16 rows and 16 columns). The row of each pressure mat at the junction between seat pan and backrest was removed due to artefacts caused by bended sensor cells. Figure 7 illustrates pressure mapping of the control condition and the two load carriage conditions for one participant included in study IV. For each frame of the trail, average contact area and contact pressure was calculated and exported to an ASCII file. The main objective of this study was to explore the effects of load carriage design and, therefore, a Wilcoxon signed-rank test was used to determine if there was a difference in median values of contact pressure and contact area between the standard and alternate load carriage conditions. Level of significant difference was set with an alpha level of $P < 0.05$. 
Figure 7. Pictures in the top row illustrate the back rest for the thee conditions while bottom row pictures represent the seat pan. These pictures represent an average of all frames for one single participant.
Ethical considerations

The studies included in this thesis are conducted with respect to ethical principles concerning research involving humans proposed in the Declaration of Helsinki (Gustavsson, Hermerén, & Pettersson, 2011; World Medical Association, 2013). All four studies have obtained ethical approval from Regional Ethics Committee in Linköping, Sweden (dnr 2010/261-31). None of the studies included any risk of physical harm to the participants.

Recruitment of participants for the three data collections was achieved with the assistance of a contact person within the Swedish Police Authority. This contact was responsible for recruiting police officers for the project and remained in contact with participants throughout. For Studies III and IV, the desired number of participants was requested by the police contact person to participate in the data collections while on duty, which, to some extent, limited the number of participants in these studies. This recruitment procedure was necessary due to the fact that police officers may not wear their uniform or mandatory equipment (e.g. weapon, radio and pepper spray) or drive police fleet vehicles if they are not on duty. This procedure of recruitment calls into question the nature of voluntarily participation and the representative selection of the population. It was the general experience of the researchers that police officers agreeing to participate in Studies III and IV were interested in the research outcomes and supportive of research which would increase knowledge about their physical and psychosocial work environment. Participants in Studies III and IV were, before participating, given both written and oral information about the study. The right to redraw from the study was clearly explained to the participants before starting the data collection.

When receiving the survey (via e-mail), participants in Studies I and II were given written information, including a description of the study aims, methods, and the right to redraw from the study. If the participant chose to answer the survey, this was interpreted as an agreement to participate in the study. Confidentiality was ensured by coding the participants and analysing the data for the whole group. This meant that no results could be traced to the individual. Participants in Studies I and II were anonymous, as it was not possible to track those who responded to the survey.
Results

The results from the four studies are presented below. Studies I and II are presented together, as these studies aim to explore the association between different work environment factors and multi-site musculoskeletal pain.

Multi-site musculoskeletal pain (Studies I and II)

The prevalence of musculoskeletal pain in the four body regions were: upper back (33.7%), lower back (43.2%), shoulders or arms (25.5%) and hips, knees or feet (38.0%). No pain was reported by 37.3% of the sample, whereas single-site pain and multi-site pain were reported as 19.7% and 41.3% respectively.

The results from the binomial logistic regression performed in Study I showed that discomfort experienced from wearing mandatory equipment was associated with an increase in odds ratio for multi-site musculoskeletal pain. The odds for discomfort experienced from wearing a duty belt was 5.42 (95% CI 4.56 – 6.43), which was almost twice that of the discomfort experienced from wearing body armour (OR 2.69 (95% CI 2.11 – 3.42)). The hypothesis stating an association between time sitting in fleet vehicles and multi-site musculoskeletal pain was rejected.

The regression analyses performed in Study II showed that high job demand and high social support were associated with multi-site musculoskeletal pain after controlling for confounders with possible associations to the outcome variable. High job demands were associated with an increase in odds ratio for multi-site musculoskeletal pain (OR 1.66, 95% CI 1.45 – 1.91) whereas high social support was found to be associated with a decrease (OR 0.72, 95% CI 0.58 – 0.90). In the second analysis, the association between the four job strain categories and multi-site musculoskeletal pain was investigated. After controlling for potential confounders high strain and active jobs were associated with an increase in odds ratio for multi-site musculoskeletal pain with odds ratios of 1.84 (95% CI 1.51 – 2.24) and 1.45 (95% CI 1.08 – 1.94) respectively.
Gait biomechanics (Study III)

Comparisons of temporospatial data across conditions showed no significant differences between load carriage designs for any of the variables: cycle time, velocity, stride length and stride width. Kinematic variables, presented as range of motion data for all body segments, were compared across the three conditions. The results showed less range of rotation in the trunk for both load carriage conditions compared to the control condition (P < 0.017). The alternate load carriage condition resulted in a greater range of rotation in the right hip compared to the standard load carriage condition during the entire gait cycle. This was also the case for the control condition but only during the stance phase (P < 0.017). Frontal plane range of motion for the right knee was significantly greater for the alternate load carriage condition compared to the control condition (P < 0.017). Sagittal and frontal plane kinetics were calculated for hips, knees and ankles during the stance phase of the gait cycle. In the sagittal plane significant differences were observed in left hip powers, left knee moments and all moments and powers for the left and right ankle joints. Ankle joint moments and powers were significantly greater for both load carriage conditions compared to the control condition with the exception of power in the right ankle (P < 0.017).

Discomfort and pressure while driving (Study IV)

Discomfort ratings were generally low (less than 10 mm) after the scores from the control condition were subtracted. Only seven items had discomfort ratings greater than 10 mm and these were only identified in the standard load carriage condition. Six of the seven items resulted in a significantly greater level of discomfort when wearing the standard load carriage condition as compared to the alternate load carriage condition. The greatest level of discomfort was caused by the duty belt in the standard load carriage condition (36; IQR 14 - 52 mm) followed by overall discomfort from sitting in the seat (19.5; IQR 7 - 44 mm) and discomfort caused by body armour (17.5; IQR 3 - 38 mm). Discomfort in specific body regions were greatest for the lower back (30.5; IQR 11 - 42 mm) followed by the upper pelvis (right 14.5; IQR 0-34 mm/ left12; IQR 1 - 32 mm), also in the standard load carriage condition.
Contact pressures were lower in all regions when participants were driving under the control condition. Significant differences between the standard and alternate load carriage condition were found for both contact pressures and contact area ($P < 0.05$). Contact pressures in the alternate load carriage condition were greater for the right thigh and upper back and lower for the lower back when compared to the standard load carriage condition ($P < 0.05$). Contact area was lower for the left thigh and upper back in the alternate load carriage condition when compared to the standard load carriage condition ($P < 0.05$).
Discussion

General discussion of the results

The overall aim of this thesis was to increase knowledge related to musculoskeletal disorders in the Swedish police by exploring the prevalence of pain and its relationship to physical and psychosocial factors in the work environment. To achieve this aim, two studies were conducted to explore associations between work environment factors specific to police and multi-site musculoskeletal pain, while two further experimental studies explored specific physical workload factors from a biomechanical perspective. Results demonstrated that musculoskeletal disorders are common among police working in active duty and that both physical and psychosocial factors related to the work environment of the police are associated with musculoskeletal pain. Duty belts worn by uniformed police were identified as a significant source of discomfort which primarily affects police in the region of their lower back and also affects discomfort experienced when sitting in fleet vehicles. In relation to biomechanical outcomes, mandatory equipment worn by uniformed police was found to have a moderate effect on walking and driving police fleet vehicles. It is anticipated that combined results from this thesis can provide the police authorities with guidance for prioritising interventions aimed at improving the work environment of the Swedish police. Specifically, findings related to load carriage design should be considered when developing alternatives to the current load carriage system and in the development of policies related to the use of mandatory equipment.

The NRC model presented earlier in this thesis was used to define variables that may contribute to the development of musculoskeletal disorders in police. The major outcome variable of interest was pain which, in this thesis, is considered to be a measurable symptom or sign of musculoskeletal disorders. The NRC model presents three major factors which may contribute, independently or in combination, to the development of a musculoskeletal disorder. These are; external loads, organisational factors and social context factors. The results of this thesis will be discussed in relation to the main outcome measure, pain, and each of the workplace factors presented in the NRC model.
Musculoskeletal pain in Swedish police

In the NRC model, musculoskeletal pain and discomfort are outcomes related to musculoskeletal disorders. In this thesis the experience of musculoskeletal pain or discomfort, has been interpreted as a symptom or early sign of a musculoskeletal disorder. It is, however, recognised that the experience of pain can be influenced by a number of other factors. These will be presented in the methodological discussion below.

Musculoskeletal pain and discomfort were frequently reported problems for Swedish police working in active duty. The prevalence of musculoskeletal pain in the lower back (43.2%) and lower extremities (38%) was greater for active duty police than in the general Swedish working population tested using the same questionnaire during the same period (32% lower back and 30% lower extremities) (Arbetsmiljöverket, 2014). These results are in contrast to those of Brown et al. (1998) who have suggested that the prevalence of lower back pain in police is not more than that experienced by the general population. In a sample of Canadian police officers, Brown et al. reported a prevalence of lower back pain in police as 41%, which is similar to the results in this thesis and subsequently suggests that there is a higher prevalence of lower back pain in the Canadian general population.

Lower back pain is the most frequently reported musculoskeletal disorder among the police, with a period prevalence ranging from 41-49% (Brown et al., 1998; T. S. Cho et al., 2014; Gyi & Porter, 1998; Jahani et al., 2002). The results presented in this thesis support these previously published findings. Given that results are consistent across a variety of countries (The United Kingdom, Korea, Iran and Canada) it is fair to assume that police working in active duty are exposed to similar workload factors. This would likely include the requirement to carry police specific equipment and long periods of sitting in vehicles. There is little evidence describing the specific work tasks of police outside the fleet vehicle.

Multi-site musculoskeletal pain was reported by 41.3% of police working in active duty. This was double the percentage single-site pain (19.7%). The consequences of multi-site musculoskeletal pain has been found to be more debilitating than single-site pain (Scudds & Robertson, 2000) and highly associated with decreased work ability, sickness absence and disability (Fernandes & Burdorf, 2016; Miranda et al., 2010; Phongamwong & Deema,
Multi-site musculoskeletal pain has not previously been investigated in police, limiting comparisons to other occupational groups such as health care sector employees and industrial workers (Freimann, Coggon, Merisalu, Animagi, & Paasuke, 2013; S. Neupane et al., 2011; S. Neupane et al., 2016; Sembajwe et al., 2013). The prevalence of multi-site musculoskeletal pain reported among employees within the healthcare sector ranges from between 39-52.3%, whereas industrial workers have a prevalence of 58%. The participants in these studies were predominately women and were, on average, between 38.7-41 years of age. Only 25.7% of the police included in Studies I and II were women and the majority (70%) of all police were under the age of 40. This could partly explain why the prevalence of multi-site musculoskeletal pain among active duty police is lower than the occupational groups who serve as a comparison. It is well documented that the prevalence of musculoskeletal disorders is higher among women and increases with age (Arbetsmiljöverket, 2014; McBeth & Jones, 2007). With current knowledge regarding the consequences of multi-site musculoskeletal pain, police working in active duty should be considered to be a group with an increased risk of having future musculoskeletal problems affecting their ability to work.

The number of police who were on sick leave due to musculoskeletal disorders at the time of data collection for Studies I and II is not known. It should subsequently be recognised that the problem of musculoskeletal pain among the Swedish police force could be greater than that which is reported in this thesis.

**External load**

The NRC model defines external loads as physical job demands, such as work procedures and equipment, which contribute to biomechanical loading of the musculoskeletal system. In this thesis, mandatory equipment borne by the Swedish police, as well as and time spent sitting in fleet vehicles, were physical exposures of specific interest as they have previously been identified by police as factors related to the development of musculoskeletal disorders (Ramstrand & Larsen, 2012). These exposures were studied by investigating the effect of different load carriage systems on biomechanical outcomes as
well as investigating the association between mandatory equipment, sitting time and musculoskeletal pain.

The experience of discomfort from wearing duty belts and body armour were both found to be significantly associated with an increased odds ratio for multi-site musculoskeletal pain among police working in active duty. The greatest association was found for the experience of discomfort from wearing a duty belt, with an odds ratio greater than five. This result lends support to previous studies which identify standard duty belts as a great source of discomfort (Czarnecki & Janowitz, 2003; Donnelly et al., 2009; Filtness et al., 2014; Holmes et al., 2013) and a perceived cause of lower back pain among uniformed police (Brown et al., 1998; Ramstrand & Larsen, 2012). Discomfort from wearing duty belts has been suggested to be related to the weight of the belt and the added bulk of the duty belt which interferes with sitting position in fleet vehicles (Holmes et al., 2013). It has also been demonstrated that discomfort from wearing duty belts is exacerbated when sitting in police fleet vehicles (Czarnecki & Janowitz, 2003; K. M. Gruevski, M. W. R. Holmes, C. E. Gooyers, C. R. Dickerson, & J. P. Callaghan, 2016). When comparing the results of previous research to the findings of this thesis, it is clear that duty belts are a considerable work environment issue for uniformed police.

Although the standard duty belt has been reported as a source of discomfort, most police agencies still use this kind of load carriage system without offering an alternative, such as a load-bearing vest. Discussions the author has held with the Swedish police have indicated that there is a resistance to use load-bearing vests due to the perception that they would give the Swedish police an overly militaristic appearance. Similar ideas have been discussed by Czarnecki and Janowitz (2003) but to date there is no evidence to support the hypothesis that load-bearing vests would have a negative influence on the public’s perception of the police.

To facilitate identification of police by members of the public, Swedish police working in active duty are required to have a unified appearance, both in terms of clothes and load carriage. This further limit the possibility for police authorities to offer an alternative to the standard load carriage system. The standard load carriage system is not flexible enough to fit all body compositions which especially becomes a problem when same type of equipment is to be used by both men and women. Women with small
circumference around the waist often experience problems fitting all police appointments on the duty belt. This result in more appointments being positioned posterior on the duty belt which subsequently is an obstacle when sitting in fleet vehicles. Having alternate load carriage systems that the police themselves could choose between would be an improvement for many police officers.

The alternate load carriage condition explored in Studies III and IV incorporated a prototype load-bearing vest which was worn on top of the standard issues body armour. When compared to the standard load carriage systems worn by police, the alternate load carriage system was found to decrease self-reported lower back discomfort when driving and contact pressure was reduced in the lower back. Similar results related to pressure distribution and discomfort have been reported by Holmes et al. (2013), who explored the use of a reduced duty belt with no appointments placed on the posterior half of the body. These results were to be expected as the source of discomfort (appointments) was removed completely. Relocation of appointments from the duty belt to the upper body might introduce new challenges. For example, a reduced range of rotation in the trunk was found for both load carriage conditions tested in Study III, while in Study IV, the load-bearing vest condition introduced a higher pressure on the upper back while driving. Reduced trunk kinematics have also been reported by Ramstrand et al. (2016) in police who wore load-bearing vests for a 3-month period. Ramstrand et al. also found that wearing body armour and body armour plus a load-bearing vest, significantly increased the abduction angle of the arms while walking. Although the biomechanical changes reported by Ramstrand et al. were found to decrease over time, the results still indicate that wearing body armour and a load-bearing vest will impose kinematic changes to the upper body. Introducing a load-bearing vest has the potential to increase strain on the shoulders and neck and carrying appointments on the anterior part of the trunk could be experienced as an obstacle when working with arms in front of the body. To date, it is not clear if relocating appointments to the upper body would simply relocate the problem from the lower back to the shoulders and neck.

While kinematic changes to the trunk and right hip have been reported in police wearing mandatory equipment the changes are relatively small and it is
likely that this is only one component in the development of musculoskeletal pain among police. It must however be kept in mind that police are subjected to this constraint in movement during their entire working time.

A major difference between the alternate load carriage condition used in Studies III and IV and the alternate load carriage condition used by Ramstrand et al. (2016) was that, in the Ramstrand study, appointments were placed in the load-bearing vest and the weapon was either placed in the duty belt or a thigh holster. In Studies III and IV, appointments in the alternate load carriage condition were divided between load-bearing vest and thigh holster with the two heaviest appointments (weapon and baton) worn in the thigh holster. In Study III, the range of rotation in the hip on the side of the body bearing the weapon was found to be less in the standard load carriage condition when compared to the alternate load carriage condition. Ramstrand et al. (2016) had a similar study design when evaluating the effect of a load-bearing vests but holster type was not controlled for and therefore only half of the participants wore a thigh holster. The weapon is typically positioned anterior to the greater trochanter which may interfere with normal rotational movement in the hip. It is however difficult to predict the long-term consequence of this and longitudinal studies exploring both belt mounted hip holsters and thigh holsters are needed.

Previous work has found a significant relationship between long periods of driving and musculoskeletal pain in police (Gyi & Porter, 1998). Time spent sitting in fleet vehicles was one of the main exposure variables investigated in Study I but in this instance no associations was found between driving time and musculoskeletal pain. One explanation for this result might be that the outcome variable used in study I was multi-site pain whereas Gyi & Porter only studied lower back pain.

Duty belts, body armour and load-bearing vests are clearly physical exposures in the workplace of police which affect biomechanical loading of the body and are associated with musculoskeletal pain. The load from mandatory equipment might be relatively light compared classical workload exposures such as heavy lifting and high frequency repetitions. It is important to remember that even small loads sustained over long periods without breaks or variation can have a significant effect on the development of musculoskeletal disorders (Toomingas et al., 2012). It must therefore be recognised that uniformed police who wear mandatory equipment for an average of 40 hours
per week are subjected to a constant exposure which can potentially lead to musculoskeletal disorders.

Organisational and social context factors

The NRC model presents organisational and social context factors as two separate entities. Within this thesis, these factors were described as psychosocial aspects of the workplace, investigated using Karasek’s JDC model and as well as an additional variable representing social support from supervisors and co-workers. As suggested by the NRC model, these factors have the potential to influence the development of musculoskeletal disorders on different levels; however, in this thesis, only the association between organisational and social context factors and the main outcome variable pain was investigated.

The results found in Study II are the first to explore the association between psychosocial workplace factors and multi-site musculoskeletal pain among police working in active duty. The categories defined as high strain and active were associated with an increased odds ratio for multi-site musculoskeletal pain. The common determinant for these two categories is high demands which was also found to be associated with an increased odds ratio for multi-site musculoskeletal pain when analysed separately. Interestingly, the majority (88%) of active duty police reported having high social support, which was associated with a decrease in multi-site musculoskeletal pain. Low control was reported by the majority (72%) but not found to be significantly associated to multi-site musculoskeletal pain. Findings confirm the previously suggested relationship between psychosocial workplace factors and musculoskeletal disorders. In the JDC model high strain is considered to be the category introducing the highest risk for reduced health and wellbeing. High strain was reported by 39.9% of police working in active duty while the corresponding values for the general working population in Sweden during the same period was 28% (Arbetsmiljöverket, 2014). This result implies that high strain is a considerable problem among Swedish police working in active duty.

High job demands have previously been found to be associated with multi-site musculoskeletal pain among occupational groups such as patient care workers, office workers and postal clerks (Herin et al., 2014; Sembajwe et al.,
2013; Solidaki et al., 2010). Although a wealth of literature has been published on occupational stress among the police, few studies have investigated its relationship to musculoskeletal disorders. When exploring job stress among Norwegian police, job pressure and lack of social support were found to be associated with an increased odds ratio for subjective health complaints (pressure OR = 1.4; lack of support OR = 1.4) (Berg et al., 2006). Subjective health complaints were represented by an index where the majority of questions were related to musculoskeletal problems and pain but also included questions examining migraines, headaches and digestive problems. Job pressure was related to the organisation of work and lack of support was related to co-workers and leadership. The items defining job pressure in the study by Berg et al. (2006) are similar to the items from the SWES used to define job demands in this thesis. Although subjective health complaints and multi-site musculoskeletal pain are two different outcome measures, the findings by Berg et al. (2006) confirm the results in this thesis.

A job situation with high job demands is characterised as having limited time for breaks, working overtime, many stressful situations, and generally having too much to do. Some of these situations contributing to a demanding work situation could be caused by a shortage of staff. Of those police officers included in this thesis, only 23% had worked in active duty more than 10 years. It could be assumed that police officers choose other jobs when the work situation becomes untenable. This results in a faster rotation of staff in active duty and fewer police officers with long occupational experience.

Gershon et al. (2009) found that perceived work stress among a sample of American police officers was associated with a number of psychological, behavioural and physical outcomes. Perceived job stress was related to a feeling of wanting to withdraw from work, feeling negative and depressed at work and feeling unsatisfied with one’s own performance at work. Among the physical outcomes, chronic back pain was found to have the greatest association to high levels of perceived work stress (OR = 2.36). In this thesis work stress is related to the organisation of work and social interactions with co-workers and supervisors whereas job stress measured by Gershon et al. (2009) represents a personal feeling of stress within the individual police officer. The findings by Gershon et al. are similar to the association between high strain jobs and multi-site musculoskeletal pain found in study II. Despite the differences in describing/defining job stress, these findings demonstrate
that high stress at work have a negative influence on different aspects of health among the police.

Methodological discussion

The theoretical framework chosen for this thesis includes two models which deal with different workplace factors that have the potential to influence the health and wellbeing. The NRC model was chosen because it suggests potential pathways for the development of musculoskeletal disorders and it was combined with the JDC model which was used to measure psychosocial workplace factors presented within the NRC model. Methods used to address relationships between factors within the NRC model are drawn from a number of disciplines and in this thesis biomechanics and epidemiology were the dominant disciplines. The scientific area of occupational health is multidisciplinary and is mirrored in this thesis by using methods from different research fields.

In this thesis, the greatest focus has been on describing how specific workplace factors might be related to the development of musculoskeletal disorders. Less attention was directed toward understanding the influence of individual factors such as family-work conflicts, leisure time activities and coping with traumatic incidents at work. Individual factors are a part of the NRC model and it is possible that the high prevalence of musculoskeletal pain reported by police could, in part, be explained by these factors.

The quantitative study design used in all four studies is a potential limitation when trying to capture the experience of pain. With the high prevalence of musculoskeletal pain reported in this thesis, it would be of interest to explore how pain affects work ability and activities of daily life. It is possible that studies exploring musculoskeletal disorders among the Swedish police from an individual perspective using a qualitative approach would be valuable in further understanding musculoskeletal disorders within this population.
Musculoskeletal pain in Swedish police

Studies included in this thesis have measured self-reported musculoskeletal pain as the outcome representing musculoskeletal disorders. This outcome measure was chosen as data were collected using a self-administered web-based survey and clinical assessment/examination of the participants was not possible. Pain can be measured using different instruments designed to describe pain intensity, frequency and/or duration (Cimmino, Ferrone, & Cutolo, 2011). The items measuring pain used in this thesis take both frequency and duration into account, but the intensity of pain remains unknown. Pain intensity is a highly subjective measure and is often considered most relevant in relation to loss of function in daily life or at work (Zanoli, Strömqvist, Jönsson, Padua, & Romanini, 2002).

The results of this thesis demonstrate that musculoskeletal pain, at least one day per week within the last 3 months, is a common problem among Swedish police. The majority of participants in Studies I and II (89%) had worked 50% or more in active duty for the past 12 months. No differences in the prevalence of musculoskeletal pain between those working 50% or more and those working 50% and less were observed. It could therefore be hypothesised that musculoskeletal pain experienced by the Swedish police is not of such intensity that it results in work absence.

The items used to measure musculoskeletal pain all come from the SWES which is an instrument used to describe the work environment of the employed population in Sweden. During the methodological development of the SWES, a number of validation studies were preformed to ensure that both question and response alternatives were constructed to give meaningful and reliable answers (Wikman, 1991). The quality of the instrument is continuously analysed by Statistics Sweden who modify or replace items when necessary.

Pain is a highly subjective experience that can be influenced by a number of factors such as pain beliefs, placebo effects, injury, mood and stress (Hush, Michaleff, Maher, & Refshauge, 2009; Tracey & Mantyh, 2007). When considering these factors in relation to the studies of this thesis, both placebo effects and stress could be factors which might be influence the experience of discomfort and pain. In Study IV, the effect of different load carriage systems was investigated in relation to experienced discomfort when sitting in vehicles. The standard load carriage system was the condition with greatest
discomfort for all items and the clear preference for the alternate load carriage system could partly be related to a placebo effect of introducing something new. In Studies I and II, musculoskeletal pain in four specific body regions was the main outcome measures. In these studies, work stress could be a factor affecting the experience of pain attributed to the work situation. High psychosocial stress have been found to be associated to neck pain (Hush et al., 2009) but, as yet, there is insufficient evidence to support an association between work stress and lower back pain (Hartvigsen, Lings, Leboeuf-Yde, & Bakketeig, 2004).

Recall of musculoskeletal pain is another factor which could influence the prevalence of musculoskeletal pain reported by the Swedish police. Previous musculoskeletal pain is poorly recalled after a number of years and is strongly influenced by having pain at the time of recall (Miranda, Gold, Gore, & Punnett, 2006). It has been demonstrated, however, that pain or discomfort for a retrospective period of 3 months is a reliable measure (Brauer, Thomsen, Loft, & Mikkelsen, 2003). As musculoskeletal pain during the last 3 months is the recall period used in this thesis it can be assumed that the answers given by the participants are reliable.

The NRC model used as a theoretical framework in this thesis incorporates both discomfort and pain as outcome measures related to musculoskeletal disorders. In the context of this thesis, musculoskeletal pain is used as an outcome measure for Studies I and II, whereas discomfort was used as the outcome measure in Study IV. The decision to use one of these constructs over the other was based upon the data collection method used in each study. Measures of pain were used when documenting the prevalence of pain in specific body regions whereas discomfort ratings were used when investigating the sitting situation in fleet vehicles. Within the context of the NRC model, the term ‘discomfort’ is used to describe a symptom of a musculoskeletal disorder. The construct of discomfort is, however, also used as an ergonomic measure to describe the response to a specific task or environment (Annett, 2002). Therefore, the construct of discomfort was also used to describe the response to wearing mandatory equipment. The items assessing the experience of discomfort from wearing mandatory equipment were developed by the research team and tested in focus groups before data collection. These items were intended to measure how many police officers experience problems from wearing their mandatory equipment. The analysis
conducted in Study I therefore included discomfort experienced from wearing mandatory equipment as an independent variable and multi-site musculoskeletal pain as the dependent variable. It is recognised that these two constructs are somewhat related, and this imposes a limitation on this thesis. The study designs used in this thesis do not allow statements to be made about causal relationships and it is therefore not possible to determine if the duty belt causes musculoskeletal pain in the lower back or if lower back pain makes the duty belt uncomfortable to wear.

**External loads**

The NRC model defines external loads as physical job demands which result in biomechanical loading of the musculoskeletal system. This thesis has focused on biomechanical loading specifically associated with body armour, load carriage systems and sitting in police fleet vehicles. Other external loads which are also relevant to consider in relation to the development of musculoskeletal disorders include physical strain at work and working in non-neutral body positions. In this thesis five items were selected, and an attempt was made to control for these factors in Studies I and II by summing the scores from all five items into a composite variable. Other ways of controlling for physical workload factors would have been to include each item as separate variables with an ordinal scale or to dichotomise them into high or low exposures.

The effect of different load carriage systems was investigated by re-distributing loads from the duty belt to a load-bearing vest and a thigh holster. This situation was evaluated by using a three-dimensional gait analysis system (Study III) and by analysing the in-vehicle seating situation with a pressure mapping technique (Study IV). Both of these biomechanical studies were conducted as experimental studies and external variables such as order of testing conditions and variation of appointments carried were controlled. Both Studies III and IV presented a number of methodological challenges; these are discussed below.

The gait analysis system used in Study III incorporates reflective markers placed on a number of anatomical landmarks to define body segments and joint axes. A major methodological challenge in this study was to develop a marker model which would allow tracking of the pelvis while police were
wearing their duty belts. The pelvis is typically defined and tracked using reflective markers placed on the left and right ASIS as well as markers placed posteriorly on the pelvis. In this case, however, the duty belt worn by police covered all three of these anatomical landmarks. In order to address this issue, the marker model proposed by Cappozzo (1997) was used with specific modifications. In the initial static measurement participant did not wear any duty belt and ASIS markers and the sacrum marker defining the segment could be placed according to the model. At the same time a rigid u-shaped cluster with three reflective makers was placed at the sacrum. This cluster was kept throughout all measurements and the reflective markers mounted on this cluster served as tracking makers for the pelvic segment in all the dynamic trails. This solution has previously been used in other studies and found to provide reliable results (Borhani, McGregor, & Bull, 2013). The pelvic cluster was placed firmly on the sacrum, thus allowing space for the duty belt. Prior to data collection this method was tested to ensure that the position of the pelvic cluster did not change between the static trail and the dynamic trails with different equipment configurations.

Another deviation from the Cappozzo model was made in the placement of markers on the right thigh where the thigh holster was positioned. In the original maker model, the three tracking makers on the thigh are placed on a rigid cluster attached to the lateral aspect of the thigh. This cluster was replaced by three makers placed on the skin on the anterior part of the thigh. The thigh is one of the body segments with the greatest soft tissue movement (Peters, Galna, Sangeux, Morris, & Baker, 2010) and firmly attaching a thigh holster that included weapon and baton to the thigh would likely introduce more movement of the soft tissues during walking. This error combined with the risk of inter-marker movement due to placement directly on the skin may have affected variables related to the right knee and hip.

The greatest methodological challenge in relation to measuring interface pressure (Study IV) while driving was that police equipment interfered with measurements. It must therefore be recognised that the interface pressure measured in the two load carriage conditions not only represents the pressure at between the body and the seat, but also pressure between mandatory equipment, uniform and seat. This data does, however, give an indication of mandatory equipment as being an obstacle for achieving an even pressure distribution on the seat pan and back rest.
Organisational and social context factors

Psychosocial factors of specific interest in this thesis were organisational and social context factors in the workplace of the Swedish police. These factors were represented by indices of the JDC model and a variable representing social support. The items included in the job demand and job control indices were taken from the SWES in accordance with previous work by the SWEA (Arbetsmiljöverket, 2014) and items included in the social support index were similar to previous work by Andersson et al. (2017). Previous work has, however, discussed that using the items from the SWES to operationalise the JDC model imposes a risk of more individuals being classified with high demands and low control when compared to the items from the Job Content Questionnaire (Magnusson Hanson, Theorell, Oxenstierna, Hyde, & Westerlund, 2008). It is possible that this also influences the results of this thesis.

In this thesis, the social support dimension was treated as a single variable dichotomised into high and low. It would have been possible to integrate this variable into the four job strain categories. This was not performed, as it affected the group sizes in a way which was not meaningful when making comparisons.
Conclusion

Swedish police have a considerably higher prevalence of musculoskeletal pain than the general Swedish working population, with the lower back being the most frequently reported pain site. A high prevalence of multi-site musculoskeletal pain places police at a higher risk of decreased work ability and sickness absence. Musculoskeletal pain in Swedish police was found to be associated with both physical and psychosocial exposures in the work environment. Of the exposures studied in this thesis, duty belts and high strain jobs were found to have the greatest association to musculoskeletal pain.

The use of a load-bearing vest and thigh holster were found to affect levels of discomfort experienced while driving fleet vehicles and range of motion in the trunk and right hip while walking.

Results of this thesis can be used by police authorities when prioritising workplace interventions, developing policies for equipment carriage and in the continual improvement process of work environment management.
Further research

• Longitudinal studies of the physical and psychosocial work environment of the Swedish police by collecting additional waves of survey material

• Deepening the understanding of musculoskeletal pain experienced by Swedish police by using qualitative methods

• Intervention studies where uniformed police wear an alternative load carriage design during their daily work over longer periods of time

• Intervention studies with physical exercise to reduce/prevent lower back pain, i.e. core exercise

• Measuring EMG of spinal muscles over time to investigate potential fatigue in the lower back

• Measuring the interface pressure between body and duty belt both while sitting and walking

• Measuring interface pressure on the upper body/shoulder and neck when relocating police appointments to a load-bearing vest
Svensk sammanfattning

Faktorer relaterade till muskel- och ledbesvär hos svensk polis


Bärande av utrustning har tidigare primärt undersöks inom militären och hos vandrarer, med fokus på design av ryggseck och viktfördelning. Även om båda variblerna har visats vara av betydelse för utvecklingen av muskuloskeletala besvär, har detta ej studerats på djupet när det gäller polisens obligatoriska utrustning. Påverkan av långa perioder av sittande i polisbil har identifierats som en fysisk faktor som kan leda till smärta i ländryggen. Hur sittsituationen i polisbilen påverkas av den utrustning som polisen bär, är i dagsläget okänt.

Det är sedan tidigare känt att stress som kan kopplas till organisatoriska och sociala faktorer i arbetet har betydelse för utvecklingen av muskuloskeletala besvär. Den psykosociala arbetsmiljön inom polisyrket är präglad av stress relaterat till både organisatoriska och sociala faktorer samt till upplevelser och traumatiska händelser som är specifika för just polisyrket. I avhandlingen har fokus varit på organisatoriska och sociala faktorer i arbetsmiljön och dess samband med muskuloskeletala smärta hos poliser.
Syfte

Det övergripande syftet för avhandlingen var att öka kunskapen om muskuloskeletala besvär inom svensk polis genom att undersöka förekomsten av smärta samt dess relation till fysiska och psykosociala faktorer i polisens arbetsmiljö.

Specifika syften för delstudierna var:

- Att dokumentera prevalensen av smärta i två eller flera områden av kroppen samtidigt hos svensk polis samt att utforska sambandet mellan upplevt obehag från utrustningen, tid sittande i polisbil och smärta i två eller flera områden av kroppen samtidigt (Studie I).
- Att undersöka sambandet mellan den psykosociala arbetsmiljön, här definierad enligt krav-kontrollmodellen, och smärta i två eller flera områden av kroppen samtidigt hos svensk polis.
- Att undersöka kinematik och kinetik under gång hos poliser som bär standardutrustning vilken inkluderar vapenhölster i utrustningsbältet, jämfört med ett alternativt sätt att bära den obligatoriska utrustningen vilken inkluderar utrustningsväst och benhölster.
- Att undersöka effekten av olika typer av utrustning på upplevt obehag vid sittande i bil samt trycket mellan kropp och bilsäte under framförande av polisfordon.

Metod

I denna avhandling har fyra kvantitativa studier genomförts för att belysa muskel- och ledbesvär bland poliser utifrån olika perspektiv (tabell 1). Dessa studier har deskriptiv, tvärsnitts- och experimentell design, där olika typer av datainsamlingsmetoder har använts. För att dokumentera prevalensen av muskuloskeletal smärta samt undersöka sambandet mellan fysiska och psykosociala faktorer i arbetet och muskuloskeletal smärta, användes data från en enkätstudie med tvärsnittsdesign i studie I och II. Enkätmaterialet analyserades genom beskrivande statistik samt binomial logistisk regression. I studie III och IV användes en experimentell design där olika utrustningssituationer testades i förhållande till biomekaniska variabler samt
ett självskattningsinstrument för upplevt obehag vid sittande i bilsätet. I studie III användes ett tredimensionellt gånganalyssystem bestående av åtta kameror och två kraftplattor för att undersöka rörelsemönster samt kraftbelastningen under gång. I studie IV användes ett tryckmätningssystem med två tryckmätningssmattor monterade i förarsätet på en standardutrustad polisbil för att undersöka sittpositionen. Ett självskattningsformulär användes utöver detta för att undersöka upplevt obehag vid sittande i bilsätet.

Tabell 1. Design, deltagare, datainsamlingsmetod och dataanalys för de fyra delstudierna i avhandlingen.

<table>
<thead>
<tr>
<th>Studie</th>
<th>Design</th>
<th>Deltagare</th>
<th>Datainsamling</th>
<th>Dataanalys</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Deskriptiv och tvärtnitt kvantitativ</td>
<td>4185 poliser i yttre tjänst</td>
<td>Enkät</td>
<td>Beskrivande statistik och binomial logistisk regression</td>
</tr>
<tr>
<td>II</td>
<td>Tvärtnitt kvantitativ</td>
<td>4185 poliser i yttre tjänst</td>
<td>Enkät</td>
<td>Binomial logistisk regression</td>
</tr>
<tr>
<td>III</td>
<td>Experimentell Kvantitativ</td>
<td>20 uniformerade poliser från en medelstor stad</td>
<td>3D gånganalyssystem</td>
<td>Friedman tvåvägs ANOVA och post hoc test</td>
</tr>
<tr>
<td>IV</td>
<td>Experimentell Kvantitativ</td>
<td>22 uniformerade poliser från en medelstor stad</td>
<td>Enkät och tryckmätningssystem</td>
<td>Wilcoxon tecken-rang test</td>
</tr>
</tbody>
</table>

Inklusionskriterierna för medverkan i studie I och II var att deltagarna skulle jobba som polis i yttre tjänst. Enkäten skickades ut via e-post till alla anställda inom svensk polis, då selektering av befattning ej var möjlig i polisens interna e-postsystem. Två kontrollfrågor ställdes för att säkerställa deltagarens befattning inom polisen. Inklusionskriterier för medverkan i studie III och IV var att deltagarna skulle jobba som uniformerad polis i yttre tjänst och ej ha haft muskel- och ledbesvär vid tiden för datainsamlingen. Deltagarna rekryterades genom en kontaktperson inom polisen.

Resultat

Resultat från studie I och II visade att muskuloskeletal smärta minst en dag i veckan under de senaste tre månaderna var ett vanligt förekommande problem bland poliser i yttre tjänst. Flest poliser rapporterade smärta i ländryggen
(43.2%) följt av smärta i nedre extremiteterna (38.0%), övre delen av ryggen (33.7%) samt axlar och armar (25.5%). Förekomsten av muskuloskeletalsmärta i ländrygg och nedre extremiteter var högre bland poliser jämfört med den genomsnittliga arbetande svenska befolkningen vid samma tidpunkt. Förekomsten av smärta i två eller flera områden av kroppen samtidigt, rapporterades av 41.3%, vilket var dubbelt så många jämfört med de som enbart rapporterade smärta i ett område av kroppen (19.7%).

Både fysiska och psykosociala faktorer var associerade till förekomsten av smärta i två eller flera områden av kroppen samtidigt. Av de fysiska faktorerna som undersöktes i denna avhandling var det upplevt obehag vid bärandet av utrustningsbältet som hade det starkaste sambandet till smärta i två eller flera områden av kroppen samtidigt (OR 5.42 [95 % CI 4.56 – 6.43]). Av de psykosociala faktorerna var det arbete med hög anspänning som hade det starkaste sambandet till smärta i två eller flera områden av kroppen samtidigt (OR 1.66 [95 % CI 1.45 – 1.91]). Högt socialt stöd var kopplat till lägre odds för smärta i två eller flera områden av kroppen samtidigt (OR 0.72 [95 % CI 0.58 – 0.90]).

Vid jämförelse av kinematiska och kinetiska variabler mellan de olika sättet att bära utrustning i studie III visade resultatet att rörelseomfånget av bålen var mindre under de två situationerna där deltagarna bar skyddsväst eller skyddsväst och utrustningsväst jämfört med kontrollsituationen. Resultaten visade även att rörelseomfånget i höger höft var mindre när vapnet bars i ett höfthölster i utrustningsbältet jämfört med när det bars i ett benhölster fastspänt på låret. Belastningen visade sig också vara högre på båda fotlederna når deltagarna bar utrustning jämfört med då de inte hade någon utrustning på sig, ett resultat som kvarstod även efter justering för utrustningens vikt.

Resultatet av tryckmätningarna som genomfördes i studie IV visade att trycket mellan ländrygg och ryggstöd minskade när utrustningens placering förändrades från utrustningsbältet till utrustningsväst och benhölster. Däremot ökade trycket i övre delen av ryggen och under höger lår för samma situation. Självrapporterat obehag vid sittande i bilsätet var generellt lågt. Mest obehag rapporterades när poliserna bar utrustningsbälte, både när det gällde sittsituationen i bilen och obehag relaterat till specifika områden i kroppen. Mest obehag rapporterades vid sittande med utrustningsbälte och gällande obehag i ländryggen.
Sammanfattning

Svensk polis som arbetar i yttre tjänst har en hög prevalens av muskuloskeletalsmärta varav ländryggen är den mest vanligt förekommande lokaliseringen av smärtan. Det finns även en hög prevalens av smärta i två eller flera områden av kroppen samtidigt vilket innebär en ökad risk för nedsatt arbetsförmåga samt sjukfrånvaro. Både fysiska och psykosociala faktorer visade sig vara associerade till smärta i två eller flera områden av kroppen samtidigt bland poliser. Av de faktorer som undersöktes i denna avhandling var det upplevt obehag från bärande av utrustningsbältet samt jobb med hög anspänning som hade starkast samband till smärta i två eller flera områden av kroppen samtidigt.

Användandet av en utrustningsväst och benhölster visade sig påverka graden av obehag vid sittande i polisbilar samt rörelseomfånget i bålen och höger höft under gång.

Resultaten av denna avhandling kan användas av svensk polis i prioriteringar av arbetsplatsinterventioner, i arbetet med att utveckla riktlinjer för bärande av utrustning, samt i det systematiska arbetsmiljöarbetet.
Acknowledgements

First of all, I would like to thank all the police officers who have participated in my studies, your contribution has been crucial for the development of this thesis.

I would also like to thank the Swedish Police Authority and the School of Health and Welfare at Jönköping University for financial support during my time as a doctoral student.

From the very beginning of this project, I have had the pleasure of working with Patrik Forsemalm, who has been deeply engaged in the health and safety work of the Swedish police. Thank you, Patrik, for always being positive, helpful and reminding me that this project must be relevant for police officers working in active duty. I would also like to thank Charlotte Råstedt, Gunilla Wallin and Liselott Hedenskog for helping me in gaining access to participants and equipment, and for the many discussions we have had.

Writing a thesis is a long process of learning and I have had amazing company along the way. I am very grateful for all the support and encouragement I have received from my supervisors. So, thank you very much Nerrolyn Ramstrand for your patience with me and for inspiring me with your energetic and effective way of working, I am really looking forward to having you as a colleague again! Roy Tranberg, you are one of a kind, and I have really enjoyed working with you. Your detailed and systematic approach to all kinds of data collection and analysis really appeals to me. Thank you for not only helping me with this thesis work, but also for always being interested in my wellbeing. I would also like to thank Elisabeth Elgmark Andersson for being my supervisor for the first half of my doctoral studies. Your contribution to the survey data collection has been very much appreciated. Finally, I would like to thank Eleonor Fransson for your help and support in the last half of my studies and for critically examining my work several times before becoming my supervisor.

I would like to thank the Research School of Health and Welfare, Jönköping University, for providing me with an excellent research and work environment. A special thanks to research coordinator Kajsa Linnarsson, who came and changed the atmosphere. Your excellent service and personality will
never be forgotten. Also, a big thanks to Bengt Fridlund, Karolina Boberg and Jan Mårtensson for making this workplace a great one.

One of the most important factors keeping me going in writing this thesis has always been my fellow doctoral students and colleagues. A big thanks to both past and present colleagues for your support and for sharing good and bad times. A special thanks to Frida Lyngnård; I have been so fortunate to have you as my friend and as a colleague! Thank you, Ann Johansson for all your love and support. Also, a special thanks to Birgitta Ander, Louise Rundqvist, Hanna Ahonen, Magdalena Stadin, Elin Ekström and Saffran Möller for the many coffee-break discussions we have had! Finally, I would like to thank Ulrika Börjesson and Katherine Stevenson for making me feel welcome as a new doctoral student, you don’t know what that meant to me.

A special thanks to my parents, Ole and Mariann, and my brother, Anders, for your unconditional love and never-ending support. I am grateful that you have always believed in me.

Finally, I would like to thank my family Anders, Ellen and Eskil. Anders, thank you for always taking my side when work has been hard. Our little family means the world to me. Ellen and Eskil, thank you for always reminding me what is most important in life ♥

69
References


70


Neupane, S., Pensola, T., Haukka, E., Ojajärvi, A., & Leino-Arjas, P. (2016). Does physical or psychosocial workload modify the effect of musculoskeletal pain on sickness absence? A prospective study among the Finnish population. *International Archives of


