Quantification and Evaluation of Physical Shoulder Exposures in Police Mobile Data Terminal Operators

By

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Authors Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Mobile police officers perform many of their daily duties within vehicles. Combined workspace inflexibility and prolonged driving exposure creates a risk for developing musculoskeletal issues. Limited research exists that quantitatively describes postural and load exposures associated with mobile police work. This study characterized officer activity during a typical workday and recommended a cruiser configuration that minimized musculoskeletal risk through laboratory quantification of physical loading during simulated police patrol tasks.

A field study captured and analyzed digital video of traffic constables (N = 10) using custom Regional Enforcement Activity Characterization Tool (REACT) software. Mobile data terminal use represented over 13% of in-car activity time and was identified as a primary site for targeted design change. A laboratory study included 20 (10 male, 10 female) participants aged 18-35 with no recent history of right upper limb or low back disorder. Five mobile data terminal (MDT) locations and two driver seat designs were tested in two simulated police patrol testing sessions in a custom driving simulator.

A self-selected mobile data terminal location reduced mean right shoulder elevation angle as well as perceived discomfort in both the low back and right shoulder relative to all other tested locations. Muscle activity was lowest at the self-selected location and current MDT location for all recorded muscles, with significant effects shown in posterior deltoid ($p < .0001$) and supraspinatus ($p < .0001$). Using a global ranking system, the self-selected location was identified as the best of all tested locations, followed by the current mobile data terminal location. The ALS driver seat effectively reduced discomfort ($p < .0001$) in the low back during a simulated police patrol session from 15.4mm in the Crown Victoria seat to 11.1mm on a VAS scale. Under these experimental conditions, a self-selected MDT and ALS driver seat reduced discomfort and physical loading compared to the current configuration.

Acknowledgements

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1.0 Introduction

Emergency services and crisis intervention personnel, including law enforcement, experience higher physical demands than those in occupations of a more sedentary nature (Anderson, Plecas & Segger, 2001). In all aspects of police work ranging from physical criminal restraint to automotive pursuit to legal documentation, officers are exposed to physical stressors that may increase their risk of musculoskeletal pain or injury beyond other occupations. Mobile police officers, generally traffic division, experience not only acute stressors in emergency response situations, but also cumulative physical exposures associated with prolonged driving. Such mobile police officers are known to experience documented musculoskeletal and performance issues (Porter & Gyi, 2002; Brown *et al.*, 2003). Occupational driving alone has been shown to increase risk for developing musculoskeletal disorders (Magnusson *et al.*, 1996), and these concerns extend to the mobile police population.

Despite research efforts regarding subjective officer questionnaire and survey responses (Kuorinka *et al.*, 1994; Gyi and Porter, 1998), few rigorously obtained data sets on the physical demands and officer acceptance of these modern advances in technology and layout exist. Additionally, quantification of the postural and load exposures is unavailable for constrained mobile police workspaces. This lack of information for modern designs motivates study of current police cruiser layouts. Effective modification of current designs should reduce physical loading and officer discomfort, but it is also important to maintain officer safety while minimally affecting job performance ability. In no way can modifications restrict the ability to perform rapid action in crises.

1.1 Role of Modern Advances in Police-Specific Technology

Introduction of modern mobile data terminal (MDT) systems has given officers means for rapid, secure access to comprehensive information (Hampton & Langham, 2005), however, biomechanical complications may arise with improved availability of information and work efficiency. The introduction of mobile data terminal systems has affected not only communication abilities, but also modified performance methods of certain aspects of police work. To create a strong, visible police presence in the community and to deter any visible crime, traffic division officers are often encouraged to complete nearly all their daily duties within the cab of the police car. In addition to physical constraints imposed by the mobile data terminal systems, cruiser design and layout flexibility is inhibited by environmental constraints including a steering wheel with only minor tilt adjustments, a rear separation cage used to secure detainees, and multiple pieces of required on-person equipment, which are typically secured with a bulky duty belt. Performing nearly all daily duties within this confined workspace likely exacerbates the postural exposures associated with occupational driving and potentially introduces additional concerns that could increase the prevalence of musculoskeletal disorders.

There has been speculation regarding the impact of these factors on the working and seated postures that officers must assume to perform their duties in the mobile environment, however, there has been limited research to quantify the postural and load exposures that relate to the constrained workspace. Given this paucity of research, it is difficult to justify intervention recommendations to improve the situation with any confidence.

1.2 Economic Importance of Identifying Risk Factors and Reducing Injury

The economic importance of addressing musculoskeletal disorders and contributing risk factors is well defined. Despite a perception of improved workplace conditions, the 2006 Ontario total premium revenue was nearly $3.4 billion for musculoskeletal disorder related claims, a 6.1 percent increase from 2005. The fourth most common site for injury (6.2% of all injuries) is the shoulder, which is superseded only by the lower back, fingers and legs. The shoulder accounted for over 5000 lost time claims in 2006, and 57115 between 1997 and 2006 (WSIB, 2006).

The phrase musculoskeletal disorder (MSD) incorporates several injury types including sprains, strains, and overuse or repetitive strain injuries. An important first step in reducing the prevalence of such injuries is identifying occupational risk factors that may increase the likelihood of their development. Once these risk factors are identified, occupational controls or design changes can be implemented and evaluated, and specific musculoskeletal disorder risk factors may be mitigated or eliminated. Such quantitative research regarding risk factors specific to the police population is limited and is non-existent concerning technological advances to the modern mobile police environment.

Identification and concurrent quantification of physical exposures will help move towards improved designs that incorporate the unique challenges of this environment. Effecting targeted design changes that maintain officer proficiency while also removing ergonomic stressors may improve workplace safety and reduce the injury-based financial burden on this population at the local, provincial, national, and international levels.

Research scarcity specific to the mobile police population demonstrates a need for investigation into the activity postures officers assume and identification of postures that present musculoskeletal risk. Subsequently, there is a need for a biomechanical investigation into shoulder and low back measures that will effectively identify cruiser configurations that minimize risk in identified activity postures.

2.0 Purposes

- To identify and characterize the most common daily activities of traffic division officers of a representative Regional Police Service
- To quantify time-series exposures in the context of officer activities in terms of absolute time and percent time of a typical daily shift and generate a time-history of officer activity postures
- To determine EMG-based estimates of relative muscle forces and cumulative muscle demand
- To determine time-series postures and model-based estimates of time-series shoulder joint moments, bone-on-bone glenohumeral contact forces, and individual and corporate muscle force and force distribution data for a simulated mobile police typing task set in varied mobile data terminal configurations
- To determine mobile data terminal location and seat type configurations within a police cruiser that may reduce discomfort for the low back and right shoulder and have the potential to reduce risk and prevalence of musculoskeletal injury among a mobile police population.

In attempting to identify a police cruiser configuration that results in the lowest physical demands, this work will either identify a preferable configuration within modern spatial constraints, or indicate a need for greater adjustability or other solutions in mobile data terminal interfaces. This in turn may warrant development and implementation of targeted, evidence-based workspace design changes. The potential value of these interventions could be magnified dramatically through their application to cruiser fleets at local, provincial, national, and international levels.

3.0 Specific Aims and Hypotheses

The primary aim of this investigation was to compare physical and psychophysical outcome measures across several police cruiser configurations. This included the following subtasks:

- Differentiating EMG-derived muscle activity levels for nine recorded muscles and EMG-based total muscle force estimates between cruiser configurations
- Differentiating model-based total muscle force and resultant dynamic moment estimates between cruiser configurations
- Comparing muscle activity levels occurring during a simulated police patrol task to literature recommendations
- Differentiating upper arm and lower back postures between cruiser configurations
- Using identified differences across outcome measures to recommend a cruiser configuration

The hypotheses of this investigation are:

1. *There will be significant differences in shoulder elevation angle across the five mobile data terminal locations*

Keyboard height has been shown to have significant effects on 2-dimensional shoulder posture during a visual display terminal typing task (Liao & Drury, 2000) and there are no significant differences in trunk, shoulder, elbow, wrist, scapula or neck protraction/retraction angles in laptop computer compared to desktop computer use (Straker, Jones & Miller, 1997). Both shoulder abduction and shoulder flexion angle increase for mouse use when compared to keyboard use (Gerr *et al.*, 2000). These studies show that even subtle task changes may result in significant postural changes, so the minor mobile data terminal configuration changes in the current study may affect posture-based demands in a police typing task.

2. *Right shoulder moment and participant shoulder discomfort will be minimized in the mobile data terminal location that minimizes shoulder elevation angle*

Middle deltoid, anterior deltoid and trapezius integrated linear enveloped EMG and integrated normalized shoulder joint moments are higher with increased shoulder flexion angle (Giroux & Lamontagne, 1992; Anton *et al*., 2001). Additionally, in dynamic reach tasks, shoulder moment has emerged as the most significant independent predictor of perceived effort (Dickerson, Martin & Chaffin, 2007).

3. *Participant ratings of perceived discomfort for the right upper limb will be minimized for the self-selected mobile data terminal location*

It is difficult to make assumptions about links between self-selected postures, joint moments and injury risk. However, self-selected postures during typing tasks have been shown to minimize operator discomfort (Babski-Reeves, Stanfield, & Hughes, 2005; Helander & Zhang, 1997), and this may extend to mobile data terminal use.

4. *Average ranks across outcome measures will show differences across mobile data terminal locations, and the self-selected mobile data terminal location will have the lowest average rank*

Due to the correlation between shoulder angle, resultant moment, and corresponding discomfort (Straker, Jones & Miller, 1997; Giroux & Lamontagne, 1992; Dickerson, Martin & Chaffin, 2006), agreement is expected in outcome measures and the mobile data terminal rankings generated. This relationship is expected to extend to the predicted and measured muscle forces as well, as they are not independent of these measures.

4.0 Literature Review

4.1 Functional Anatomy of the Shoulder Complex

The combination of sternoclavicular, acromioclavicular, glenohumeral, and scapulothoracic articulations allows for complex shoulder motions that are greater than those in other body joints. This motion potential is highlighted by abduction (~170°), adduction, forward flexion (~160°), extension (~50°), internal rotation (~70°) and external rotation (~90°) (Boone & Azen, 1979), (Figure 1).

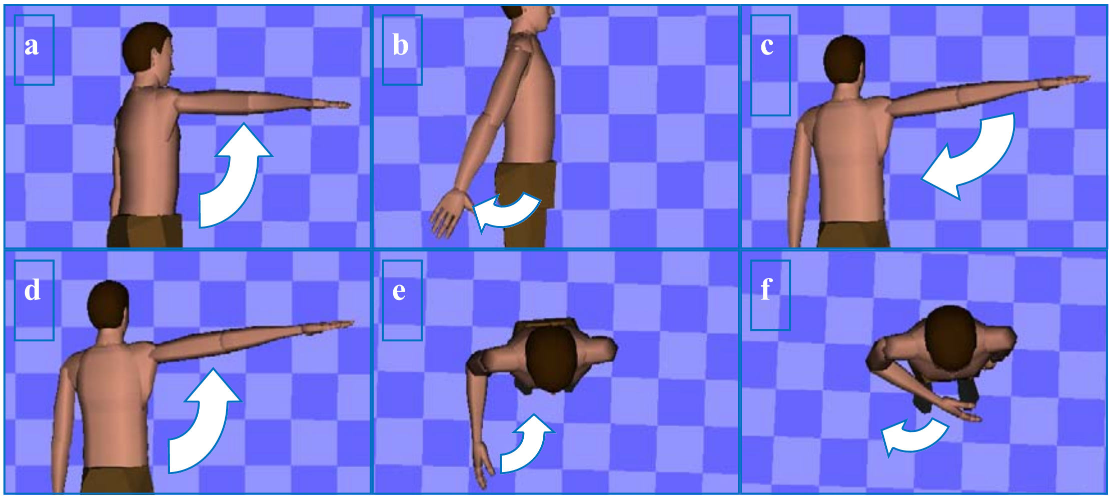


Figure 1: Articulations of the human upper arm. A) flexion, B) extension, C) adduction, D) abduction, E) internal rotation, F) external rotation.

The unparalleled motion of the shoulder girdle goes beyond these six gross movements and can be isolated to each of the four major articulations. The sternoclavicular joint (Figure 2a) contributes to elevation and depression, protrusion and retraction, and upward and downward rotation (Rockwood *et al.*, 2004) The acromioclavicular joint is the site of three-dimensional articulation between the distal end of the clavicle and the acromion process of the scapula (Figure 2b). The scapulothoracic surface allows for five degree of freedom motion, enabling glenoid positioning by way of planar superior, inferior, medial and lateral translation along the torso (Figure 3a), and rotations about the sagittal plane, frontal plane, and transverse plane (Figure 3b-d).

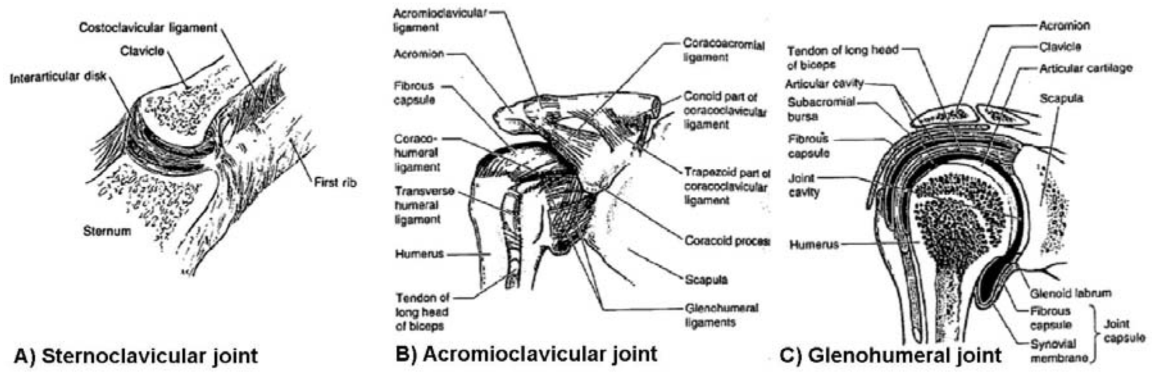


Figure 2a-c: Joint configuration and ligamentous support at the sternoclavicular, acromioclavicular, and glenohumeral joints. [from Rockwood *et al.* (2004), p. 39; Moore & Dalley (2006), p. 854]

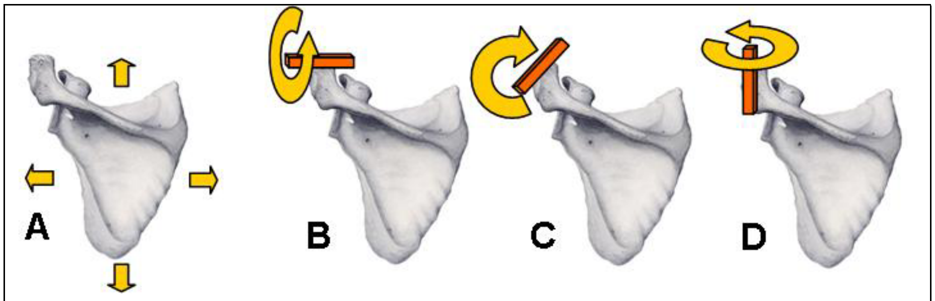


Figure 3: Translational and rotational motions of the scapulothoracic joint. [scapular image from Culley, 2008]

The glenohumeral joint accounts for the majority of the abduction (150°), flexion (180°), and internal/external rotation (90°/90°) of the shoulder complex (Rockwood *et al*., 2004). These contribution possibilities make it difficult to isolate or attribute overall glenohumeral motion to any given mechanism, but their combination and geometric interaction allow for remarkable range of motion (Rockwood *et al*., 2004).

4.2 Shoulder Stability and Injury Potential

Directly related to the considerable range of shoulder articulation is low intrinsic stability. Several factors including articular version, labral contact, intra-articular pressure, ligament support, and joint adhesion (Rockwood *et al.,* 2004) contribute to the static stability of the glenohumeral joint, but critical to dynamic stability is active muscular contraction. In injured populations, weakness of the rotator cuff muscles (supraspinatus, infraspinatus, teres minor and subscapularis), in particular, are attributed to reduced joint stability and tissue injury.

Prolonged activity or exercises, such as an occupational task in a fixed position, reduce the ability to generate muscular tension through both metabolic changes and impaired activation (Fitts *et al.*, 1982). High level or long duration exertions induce a series of metabolic alterations including lactic acid formation, an increase in inorganic phosphate, a decrease in phosphocreatine, an increase in calcium concentration and a decrease in rate of ATP hydrolysis (Chaffin, Andersson & Martin, 2006). These changes reduce the efficiency of cyclic cross-bridge formation and create a decline in the ability to produce muscular force. With the fatigue produced during prolonged static exertions, a decrease in voluntary motor drive and muscle force reduction is induced. Action potential propagation failure, neuromuscular junction transmission error, and action potential magnitude reduction are all possible factors responsible for these activation errors (Chaffin, Andersson & Martin, 2006). In general, muscle fatigue prompts significant changes in muscle activation patterns and recruitment ordering, and produces significant reduction in force production (Gorelick, Brown & Groeller, 2003).

These fatigue effects generate both stability and postural issues specific to the shoulder. Scapulothoracic and glenohumeral kinematics are altered, with increased levels of fatigue altering coordination strategies in order to compensate for localized effects (Ebaugh, McClure & Karduna, 2006; Voge & Dingwell, 2003). Onset of this fatigue may develop into an imbalance between the superiorly directed forces of the deltoid and the stabilizing effects of the rotator cuff and glenoid concavity compression (Wong *et al*., 2006). This imbalance may lead to superior migration of the humeral head and eventual rotator cuff weakness (Deutsch *et al*., 1996). In addition, muscle fatigue interferes with joint position sense (proprioception) and reflexive rotator cuff activation may be impaired by the loss of normal muscle coordination (Carpenter, Blasier & Pellizzon, 1998).

4.3 Use of the Mobile Data Terminal and Effect on Modern Police Work

The introduction of mobile computing has influenced a number of public and private industries. Among the leading governmental users of such technologies are police and criminal justice organizations, since many of them need mobile information to facilitate law enforcement activity (Agrawal, Rao, and Sanders, 2003).

In the police context, introduction of these systems has created several occupational task and performance modifications. With previous systems, officers obtained information primarily through radio dispatch procedures. The efficiency of many of the tasks they performed was entirely dependent on the performance and availability of radio dispatch and desk clerk staff. Dependence on a cumbersome procedure based on radio dispatch resulted in unacceptably high latency in decision making.

Introduction of modern mobile data terminals (MDTs) has given officers means for rapid, secure access to comprehensive information regarding license and registration, proximity of criminal activity, and real time global positioning (GPS), while considerably reducing the volume of radio traffic and associated complications (Hampton & Langham, 2005). Comparative figures before and after the introduction of police mobile data terminals show a substantial decrease in required time for plate checks, issuing of summons and warrant execution tasks. Time saved, as a result of using these terminals was equivalent to work performed by 68 officers, or approximately 10% of the patrol force (Agrawal, Rao, and Sanders, 2003) (Table 1).

Police use of MDTs has enabled better communication, which gives officers greater access to necessary information and decreases time required to perform communication-based tasks. These factors are shown to have a significant positive impact on both the job satisfaction of officers and, most critically, effective job performance (Hampton & Langham, 2005).

Table 1: Comparative statistics before and after using MDTs (Agrawal, Rao & Sanders, 2003).

Task	*Pre-MDT (number per year)*	*Post-MDT (number per year)*	*Redeployment Equivalent (officers per year)*
Plate checks	177 833	260 001	61.74
Execution of summons	31 314	33 663	2.43
Execution of warrants	1 011	1 251	4.67

The mobile data terminal systems have several functions that are used in a highly variable manner across officers and days. Evidence of the order, frequency and duration that these functions are used is a critical aspect of mobile data terminal system evaluation. A mobile data terminal usage log over a 4-hour period showed usage distribution for both single and double-crewed vehicle in an urban traffic patrol unit

(Hampton & Langham, 2005). Police National Computer inquiries for vehicles or names (PNC vehicle, PNC name) represent approximately 60% of mobile data terminal usage, whereas dispatch communications (remote database update, remote database query, incident list, assigned incident) represent approximately 35% of usage (Figure 4).

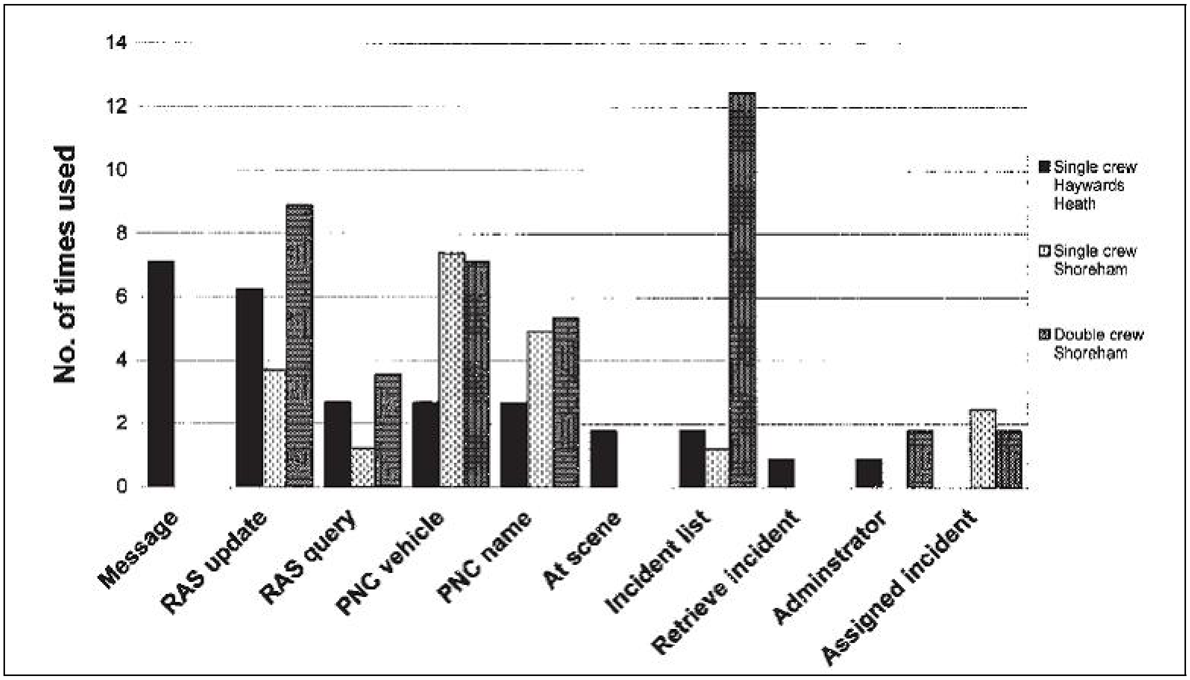


Figure 4: Normalized MDT function usage over a 4-hour period [from Hampton & Langham (2005)]. RAS refers to Remote Access Server (remote access to police database).

4.4 Investigations of Police Officer Discomfort and Influence on the Cruiser Design Process

Investigations into the occupational stressors specific to the police community are scarce. Very few studies document the physical exposures (Mirbod *et al.*, 1997) and the muscular disorders (Brown *et al.*, 2003; Gyi & Porter, 1998) that officers experience. Conclusive geometrical and biomechanical evidence of physical stressors have not yet emerged from such studies, but subjective officer questionnaire and survey responses clearly indicate prevalence of pain and discomfort specific to the mobile police population. Brown *et al.* (2003) investigated the low back pain prevalence among Royal

Canadian Mounted Police officers with questionnaire responses regarding experience with back pain, exposure to risk factors, and opinions about potential risk factors. The primary goal of the investigation was to assess the validity of the perception that the patrol car seat and duty belt cause a higher rate of low back pain. Chronic or recurring low back pain problems were reported in 54.9% of respondents and 8.5% of those reported no back pain prior to joining the RCMP. However, nearly half the sample did not wear a duty belt or drive for over half the working day. These results give the impression of similar low back pain prevalence in both this RCMP sample and the general population and underestimate the magnitude of the negative effect of equipment unique to mobile police work. These results conflict with *a priori* knowledge provided by other investigations.

Using similar interview-based methods, Gyi and Porter (1998) investigated musculoskeletal troubles in all body areas among a police patrol group with high driving exposures and a group with low driving exposures. Participant responses showed that officers whose job mainly involved driving also experienced more low back trouble over the last 12 months than those whose job primarily involved sitting (not driving), standing and lifting tasks. Further, greater levels of low back, shoulder, hand, and wrist problems were reported with increased exposure to occupational driving. These results agree with previous conclusions of increased risk of low back pain risk with occupational driving exposures.

Additional work has been done with the police population investigating psychological stress levels and physical evidence of them (Anderson, Litzenberger and Plecas, 2002; Deschamps *et al.*, 2003). These studies cite length of police service, officer rank, marital status, age and leisure activities as key determinants of occupational stress levels. Though these factors may have some influence on physical stressors, they provide little confirmation or direction towards biomechanical evaluation.

With the lack of biomechanical evidence of physical stressors, officer participation in workplace design may elicit qualitative solutions to police musculoskeletal disorder prevalence. Kuorinka *et al.* (1994) aimed to determine whether a participatory process for improving the interior of the patrol car could be established and, whether the process of participation influenced the perception of the police officers in LBP-related issues. Two groups (low back pain present and absent) were asked to improve the patrol car to better suit the job giving special attention to back disorders. Although this investigation engaged some general areas of concern (driver seat, communication devices, driver workspace), the specific aim was to compare the performance of groups. Minor differences were seen in design priorities as the LBP groups tended to stress posture-related items, which may indicate that the process of participation will guide design changes to alleviate direct officer concerns.

Given the evidence of the prevalence of musculoskeletal pain among police populations, recent investigations have sought to identify specific tasks, postures and equipment interfaces as possible risk factors. In a two phase study, Donnelly, Durkin and Callaghan (*in press*) investigated both officer discomfort and the efficacy of an active lumbar system (ALS) to reduce discomfort. Firstly, low back support, computer use and duty belt use were identified as primary areas of officer discomfort through questionnaire responses related to seat features, occupational equipment, tasks, and specific body regions. Secondly, officer discomfort was assessed using both a standard automobile seat and a seat equipped with an active lumbar system as well as foam structural modifications. The active lumbar system seat had significantly lower low back support discomfort levels than the control seat (Figure 5) (R7C and R12C being control seat use and R7A and R12A being ALS seat use). The findings of this study warrant further investigation about and use of modified police seating. This seating should maximize adjustability within the fixed range of the current police cruiser configuration and accommodate personal equipment worn by mobile officers, specifically the duty belt and protective vest.

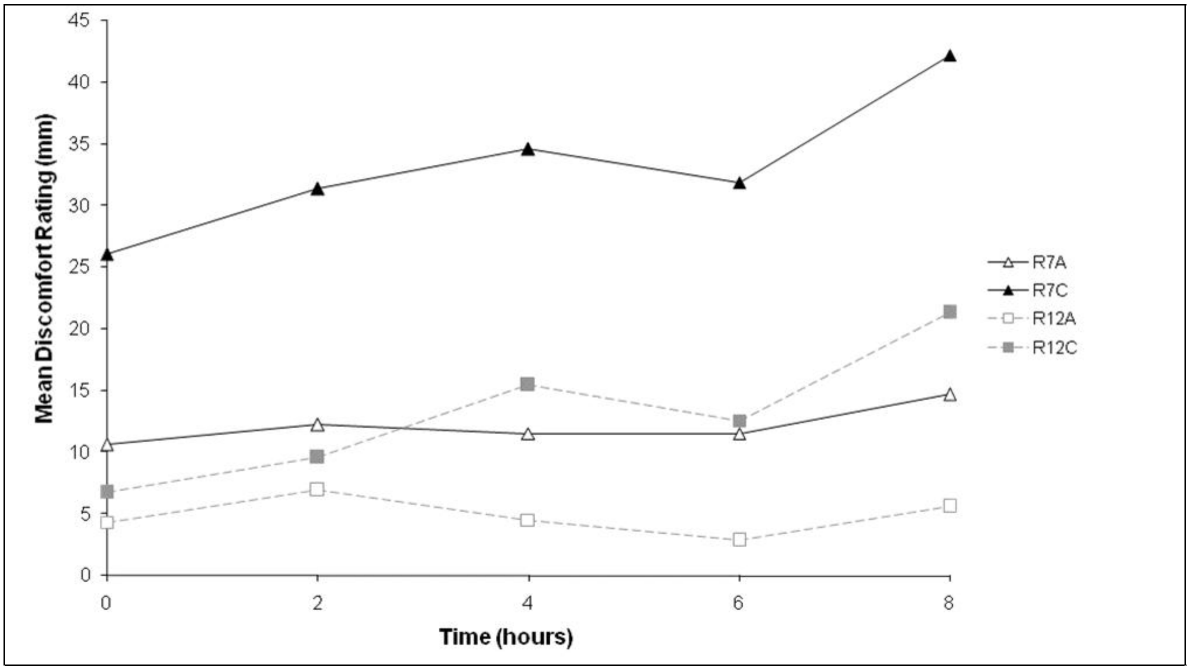


Figure 5: Mean time-varying responses of body region discomfort when using ALS vs. control seat (R7 = lower back, R12 = upper pelvis; A and C refer to the ALS or control seat, respectively) [from Donnelly, Durkin and Callaghan (in press)]

Present work with subjective officer posture and load exposure assessments by McKinnon, Callaghan, and Dickerson (*submitted for publication*) has further explored officer discomfort levels and solicited suggestions regarding equipment locations. The primary concerns with officers focus on the placement and adjustability of the mobile data terminal:

- *"Laptop positioned too high – have to raise arms – extra tension in shoulders"*
- *"Perhaps a more portable base so the user has more position options."*
- *"The laptop night light base is in a position that presses against my right knee at all times."*
- *"The laptop blocks access to all temperature controls and emergency lights. Radio microphone is in an awkward spot to access without reaching around steering wheel."*
- *"Laptop needs more adjustability and should be placed a little further from the driver. Newer stations don't have height adjustability."*
- *"Being able to adjust the laptop to a preferred position."*
- *"Typing position needs to be more ergonomic to avoid a constant twist movement of wrist. Contributes to hand-arm discomfort."*

4.5 Prolonged Sitting and Occupational Driving as an MSD Risk Factor

Extensive research has been conducted on the effect of prolonged sitting on the lumbar spine and the associated risk for developing low back pain (Makhsous *et al.*, 2003; Magnusson & Pope, 1998). Through these efforts, many advocate interrupting bouts of prolonged sitting with non-sitting tasks, and recommendations for positions to minimize lumbar loading have been developed. In general, such research conclusively demonstrates that occupational drivers are at an increased risk for developing musculoskeletal disorders. These concerns apply to various occupational driving task sets and certainly extend to the mobile police population. However, to understand the police risk factor set, the risks of occupational driving must be acknowledged.

In addition to risks associated with prolonged seated postures, there are many reasons why a high prevalence of back pain could be expected specifically among occupational drivers. For example, a fixed posture, vibration, loss of lumbar lordosis, asymmetric forces acting on the spine and periodic lifting may be factors associated with the occupational task set. Demonstrating the potential role of factors extrinsic to prolonged sitting, Kelsey & Hardy (1975) showed the relative risk of acute herniated lumbar disc while driving was twice as high as when sitting in a chair, regardless of the type of chair.

Other outcome research supports the notion of occupational driving in general as a musculoskeletal risk factor. Most notably, 25% of all drivers and 66% of all business drivers suffer from some low back discomfort (Porter, Porter & Lee, 1992). This driver discomfort can be directly associated with amount of driving exposure, as discomfort has been found to be more prevalent with increased time driving and less discomfort reported in drivers of cars with more adjustable features, such as steering wheel adjustment (Porter, Porter & Lee, 1992). Further work by Porter & Gyi (2002) confirmed a significantly higher frequency of reported discomfort, notably in the low back and neck, as annual mileage increased (Figure 6). The prevalence of wrist/hand trouble was also most frequently reported with high exposure to driving. An important observation that has guided subsequent research with occupational driving is that drivers of cars with the most adjustable driving packages were also those with less sickness absences or reported discomfort (Porter, Porter & Lee, 1992). This may suggest that elimination of postural constraints and investigation into individual responses to minimize pain could play essential roles in limiting the adverse effects of prolonged sitting.

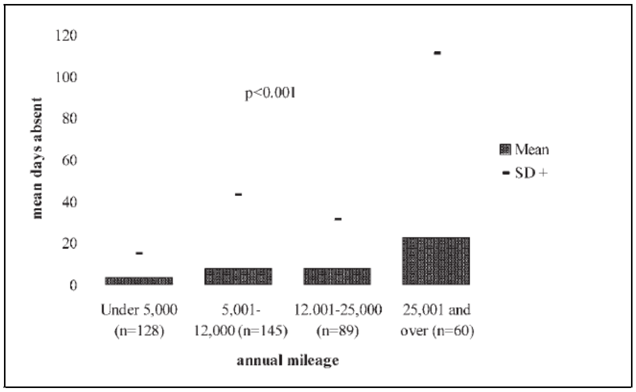


Figure 6: Number of days absent from work with low back trouble for car drivers according to annual mileage (n=422) (Porter & Gyi, 2002).

Investigations into these individual responses to prolonged sitting and resulting discomfort have shown that posture selection and interactions with a seated environment are highly population dependent. Dunk and Callaghan (2005) investigated gender effects using three 15-minute typing tasks performed by both male and female participants on four selected office chair designs with varied seat back and pivot characteristics. Male and female participants adopted different lumbar spine, pelvis and trunk angles, regardless of the chair design used. Females sat with more pelvic anterior rotation, less lumbar spine flexion and less trunk flexion than males. These results may suggest that males and females are exposed to different loading patterns through different muscle force distribution, activation timing, and segmental postures (Dunk & Callaghan, 2005). This variation in loading makes it difficult to generalize injury pathways, measures of injury risk, and recommendations for reducing injury risk.

These seated interactions are also diverse in terms of where individual responses to prolonged sitting occur. Reed *et al.* (2000) investigated the effect of seat height, steering wheel position and seat cushion angle on whole-body driving posture. A key finding from this study was that postural adaptations to changes in the layout of the driving task are accomplished primarily by changes in limb posture, whereas torso posture remains largely unaffected. This suggests that loading in the upper limb, specifically the shoulder, will be increased in peripheral tasks of an occupational driving task set and concerns with prolonged sitting are not limited to the lower back.

Static loads in the upper limb during prolonged occupational sitting present further risk to musculoskeletal injury (Magnusson & Pope, 1998). Previous investigations into upper limb loading have shown a high odds ratio in keyboard typing tasks with and without intermittent rest periods (Hagberg & Sundelin, 1986). A postal questionnaire of machine operators showed some occurrence of painful neck and shoulder symptoms in 81% of seated machine operators, with work in twisted or bent postures being significant risk indicators (Tola *et al*., 1988). In general, extended upper limb exposures to flexed or abducted postures in these occupational tasks increase cumulative shoulder moment (Nussbaum *et al*., 2001). The increased muscular load associated with this moment increase may induce local muscular fatigue and present high risk for upper limb problems (Nussbaum, 2001). Through loss of intrinsic joint stability, kinematic dysfunction, and decreased force production (Armstrong *et al*., 1993; Magnusson & Pope, 1998), there is a subsequent possibility of muscular strain, impingement or tendonitis (Chaffin, Andersson & Martin, 2006).

4.6 Surface Electromyography of the Shoulder Musculature

Estimations of both corporate and individual muscle forces and their relative contributions are essential to understanding the mechanism of mobility and stability in the shoulder for a given action (Chang *et al.*, 2000). Currently, no generally available methods of non-invasive muscle force measurement exist, thus, indirect and mathematical methods are often used to predict muscle forces. Modeling approaches driven by electromyography (EMG) are a typical means for such muscle force estimates.

Surface EMG presents a non-invasive, inexpensive, and repeatable indication of muscle activity level within and between participants. In the case of this current study, surface EMG can act as a tool to compare muscular demand between different police cruiser configurations. Indwelling EMG does offer some advantages to surface EMG.

Surface electrodes have a relatively large pickup volume, which may result in more signal, but may collect confounding data from adjacent muscles or muscle elements (DeLuca, 1997). Also, with highly dynamic movements, skin movement over a given muscle belly may disrupt EMG signal quality (DeLuca, 1997). However, given the nature of a simulated police patrol task set, surface electrodes are the most appropriate choice for the current study as they offer full participants movement and simplified application procedures.

Lower back, neck and upper limb muscles are all active in typing tasks at visual display units, with *m*. upper trapezius showing the highest absolute RMS EMG amplitude (Kleine *et al*., 1999). A police mobile data terminal typing task set differs from a standard clerical setting in that keyboard location is placed laterally and anteriorly from the body. This results in increased elbow flexion and extension, shoulder flexion, abduction, and external rotation for hand positioning. Past investigations have primarily looked at activity in the neck musculature (Hagberg & Sundelin, 1986; Hermans & Spaepen, 1997; Visser *et al*., 2000); however, it will be beneficial to record the active muscles for each of these actions unique for police mobile data terminal typing tasks. Thus, surface electromyography sites in the current study will include shoulder flexor, extensor, abductor and lateral rotator, and elbow flexor musculature (Table 2) in addition to *m*. upper trapezius and proposed synergists for each of these movements.

Table 2: Movements of the Glenohumeral Joint [*adapted from* Moore & Dalley (2006), p. 857

Movement (function)	**Prime Movers**	**Synergists**
Flexion	Pectoralis major; anterior deltoid	Coracobrachialis (assisted by biceps brachii)
Extension	Posterior deltoid	Teres major
Abduction	Middle deltoid	Supraspinatus
Lateral rotation	Infraspinatus	Posterior deltoid; teres minor

4.7 Estimation of Shoulder Joint and Tissue Loading

The etiology of shoulder musculoskeletal disorders is highly dependent on the loads that occur at the tissue level. Measurements of joint postures, electromyographical signals and muscle force production have been prevalent in shoulder research, but reliable methods of tissue load determination have historically been in question. Past models have used postural and external force data to generate muscle force estimates and improve understanding of load distribution (Hogfors, Karlsson & Peterson, 1995). However, they mostly apply to static or quasi-static situations. Recent efforts (Dickerson, Chaffin & Hughes, 2007, 2008) have developed the understanding of shoulder function and delineated four linked stages for rigorous tissue-level shoulder demand estimation: 1) musculoskeletal geometry reconstruction, 2) external force and moment calculation, 3) internal muscle force prediction method, and 4) communication of resultant muscle forces (Dickerson, 2008).

The shoulder loading analysis modules (SLAM) model (Dickerson, Chaffin & Hughes, 2007) incorporates intersegmental dynamics, population scalability, rapid geometric depiction and empirical shoulder stability constraints into a computational model, and allows integration with commercial ergonomic software. These features make it appropriate for use in quantification of physical exposures in a mobile police occupational task set.

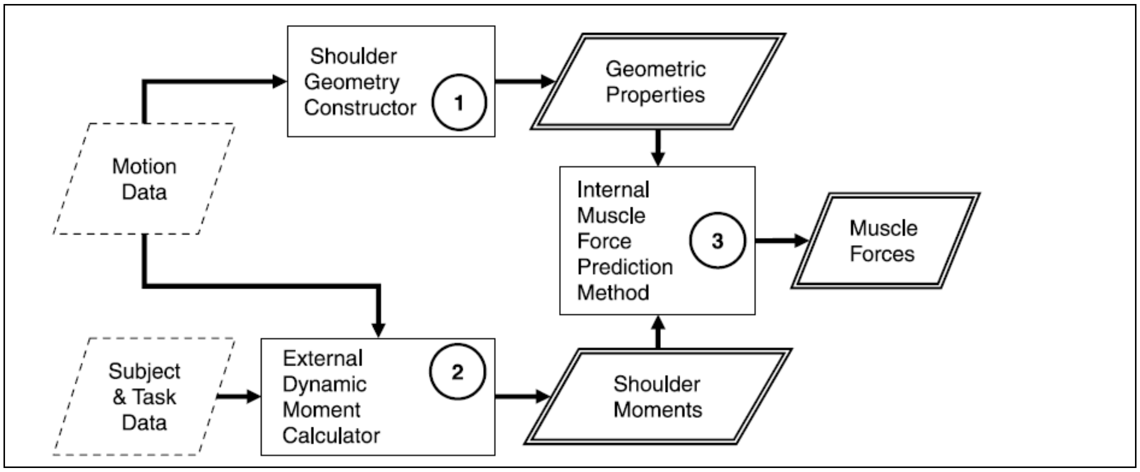


Figure 7: Data flow through the mathematical shoulder model [from Dickerson, Chaffin & Hughes (2007)].

Model inputs are three-dimensional motion data, anthropometric data, and external task load data, (Figure 7). Motion data generates intrinsic shoulder geometry, and subject, task, and motion data combine to calculate external dynamic moments through an inverse dynamics solution. These intermediate values are subsequently used as inputs into an optimization-based muscle force distribution algorithm. Calculated time-series outcome measures include postural data, joint moments, externally generated and bone-on-bone joint forces, and individual and corporate muscle forces and force distributions (Figure 8).

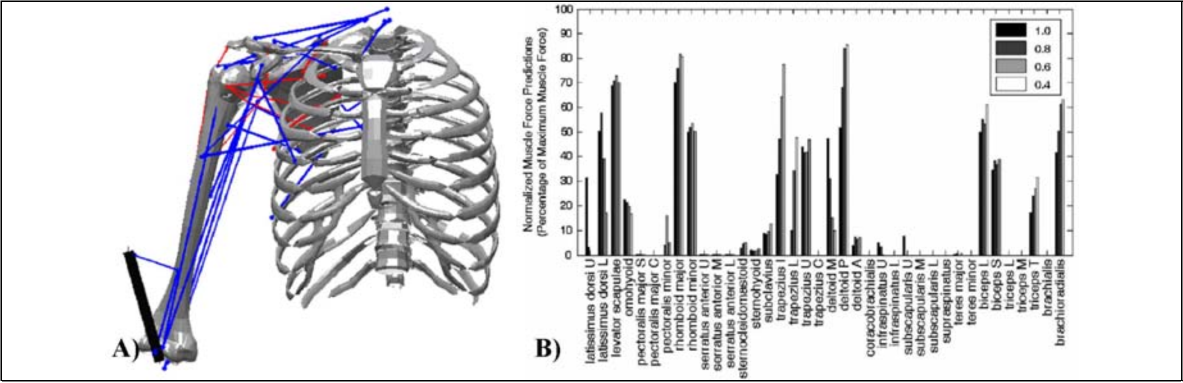


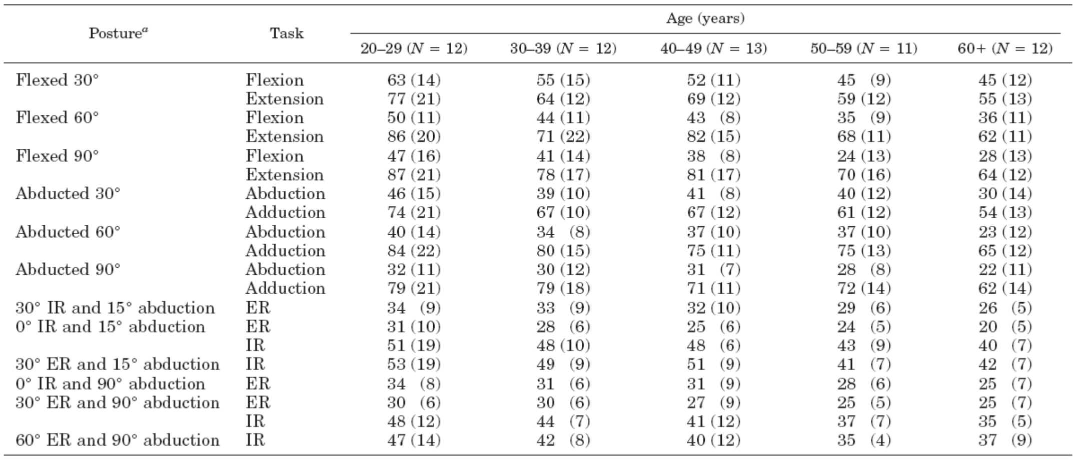
Figure 8: SLAM outcome measures. A) Depiction of glenohumeral internal geometry, including muscle elements, B) Normalized muscle force predictions with stability multiplier varied from 0.4 to 1.0. This stability multiplier influences muscle activation levels for different load/posture combinations (Dickerson, Chaffin & Hughes, 2007).

4.8 Normative Shoulder Strength Limits as Means for Evaluating Police-Specific Joint Moments

Multi-directional shoulder strength limits, a fundamental component of shoulder functional capacity, are important determinants of a workers' ability to perform a task. Several studies have investigated normal isokinetic strength values for specific populations such as baseball pitchers (Wilk, Andrews & Arrigo, 1995; Wilk *et al.*, 1993), and isometric strength values among young, healthy populations (Otis *et al.*, 1990). Though these studies provide excellent insight into maximal shoulder functional capacity, it is difficult to justify its use as a standard for occupational application.

To investigate occupational task limitation values and be fully representative of an industrial population, shoulder strength databases must be free of gender restrictions and include wide age, height and mass ranges. Hughes *et al.* (1999) tested shoulder strength under isometric conditions and reported values for 120 subjects with a focus on age-related changes. An isokinetic dynamometer was used with the elbow secured at 90° to ensure testing of isolated maximum shoulder torque. Peak maximal effort torque was obtained for twenty unique exertion conditions (Table 3). These procedures developed a normative database of isometric shoulder strength for shoulder flexion, extension, abduction, adduction, internal rotation, and external rotation. Such a complete database with articulation and subject variation is essential for comparison of occupational task demands and determining a male or female workers' age-dependent ability to perform a task.

Table 3: Mean dominant-side isometric strength measurements for males stratified by age.



Posture[a]	Task	Age (years)				
		20–29 (N = 12)	30–39 (N = 12)	40–49 (N = 13)	50–59 (N = 11)	60+ (N = 12)
Flexed 30°	Flexion	63 (14)	55 (15)	52 (11)	45 (9)	45 (12)
	Extension	77 (21)	64 (12)	69 (12)	59 (12)	55 (13)
Flexed 60°	Flexion	50 (11)	44 (11)	43 (8)	35 (9)	36 (11)
	Extension	86 (20)	71 (22)	82 (15)	68 (11)	62 (11)
Flexed 90°	Flexion	47 (16)	41 (14)	38 (8)	24 (13)	28 (13)
	Extension	87 (21)	78 (17)	81 (17)	70 (16)	64 (12)
Abducted 30°	Abduction	46 (15)	39 (10)	41 (8)	40 (12)	30 (14)
	Adduction	74 (21)	67 (10)	67 (12)	61 (12)	54 (13)
Abducted 60°	Abduction	40 (14)	34 (8)	37 (10)	37 (10)	23 (12)
	Adduction	84 (22)	80 (15)	75 (11)	75 (13)	65 (12)
Abducted 90°	Abduction	32 (11)	30 (12)	31 (7)	28 (8)	22 (11)
	Adduction	79 (21)	79 (18)	71 (11)	72 (14)	62 (14)
30° IR and 15° abduction	ER	34 (9)	33 (9)	32 (10)	29 (6)	26 (5)
0° IR and 15° abduction	ER	31 (10)	28 (6)	25 (6)	24 (5)	20 (5)
	IR	51 (19)	48 (10)	48 (6)	43 (9)	40 (7)
30° ER and 15° abduction	IR	53 (19)	49 (9)	51 (9)	41 (7)	42 (7)
0° IR and 90° abduction	ER	34 (8)	31 (6)	31 (9)	28 (6)	25 (7)
30° ER and 90° abduction	ER	30 (6)	30 (6)	27 (9)	25 (5)	25 (7)
	IR	48 (12)	44 (7)	41 (12)	37 (7)	35 (5)
60° ER and 90° abduction	IR	47 (14)	42 (8)	40 (12)	35 (4)	37 (9)

*from Hughes, Johnson, O'Driscoll and An (1999).

A similar strength database was developed for 3DSSPP (University of Michigan, Ann Arbor, MI) and integrated into the Jack Task Analysis toolkit. Past investigations into isokinetic and isometric strength were the basis for this database (Clarke, 1966; Kumar, Chaffin & Redfern, 1988).

4.9 Prolonged Occupational Exertion Guidelines

Past investigations have attempted to develop standards regarding safe characteristics for prolonged work. Isometric endurance time has been the most common measure of local muscle fatigue effects with the assumption that endurance time sufficiently integrates and describes fatigue, discomfort and injury risk (Rohmert, 1973; Jonsson, 1978; Dul, Douwes & Smitt, 1994). These efforts make conclusions under the assumption of a direct relationship between endurance time and relative muscular effort (% MVC). A commonly used work design guideline is the Rohmert Curve (Figure 9) which defines muscular effort below 15-20% is sustainable for an entire working shift (Rohmert, 1973). Other work has improved the fidelity of such models showing isometric endurance time to be dependent of load, but not gender or age (Mathiassen & Ahsberg, 1999). Recent and similar investigations, however, have found the Rohmert Curve may overestimate endurance times for exertions less than 45% MVC and underestimate times for exertions greater than 45% MVC (Garg *et al.*, 2002)(Figure 9).

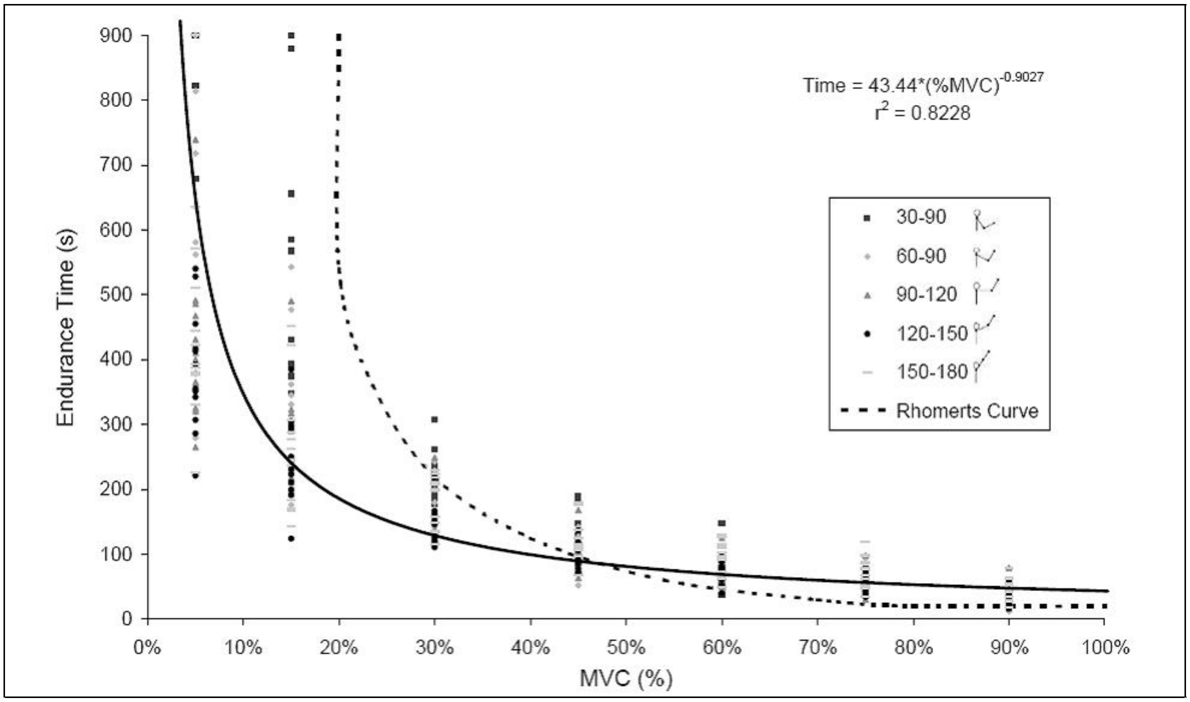


Figure 9: Endurance time against % MVC for the five different shoulder postures and seven different % MVCs [from Garg *et al*, 2002].

The extensive investigations into fatigue and endurance time during sustained pure static contractions are certainly beneficial in developing guidelines that minimize risk, however, a large proportion of occupational tasks, though prolonged, are dynamic, repetitive or intermittent (Iridiastadi & Nussbaum, 2006). An amplitude probability distribution function (APDF) quantifies cumulative muscle activity in relation to acceptable working guidelines. Load limits are defined based on the 10th, 50th, and 90th probability percentiles, which relate to static, mean and peak activity levels, respectively (Jonsson, 1978). Acceptable guidelines are 2-4%, 12-14%, and 50-70% MVC for static, mean and peak, respectively (Jonsson, 1978; Mathiassen & Winkel, 1991). Alternatively, the Dul, Douwes & Smitt (1994) model is a work-rest model, which estimates the mean remaining endurance capacity of a static posture during and immediately after a work-rest schedule. Though this model incorporates the repetitive nature of many occupational tasks, it still only describes work in static postures and fixed external forces.

Due to the complex nature of dynamic occupational tasks, specific relationships between muscle fatigue development and changes in task parameters are not clear, making task evaluation difficult (Iridiastadi & Nussbaum, 2006). At present, EMG-based muscle fatigue and task evaluation methods are among the best available options. Though fatigue assessment is not trivial, it can be monitored and quantified using EMG.

In the current study, both real and simulated police patrol tasks are highly dynamic and relatively unpredictable. Assumptions of static, sustained task parameters are not appropriate, thus cumulative activity and relative effort measures are preferred assessment criteria. Though no absolute safety thresholds exist, muscle force (and corresponding cumulative muscle stress), joint posture, and muscle activity values will be compared between different cruiser configurations in an attempt to minimize those measures. Because simulated patrol timelines were developed from observational data, it is appropriate to evaluate overall muscle activity with an amplitude probability distribution function.

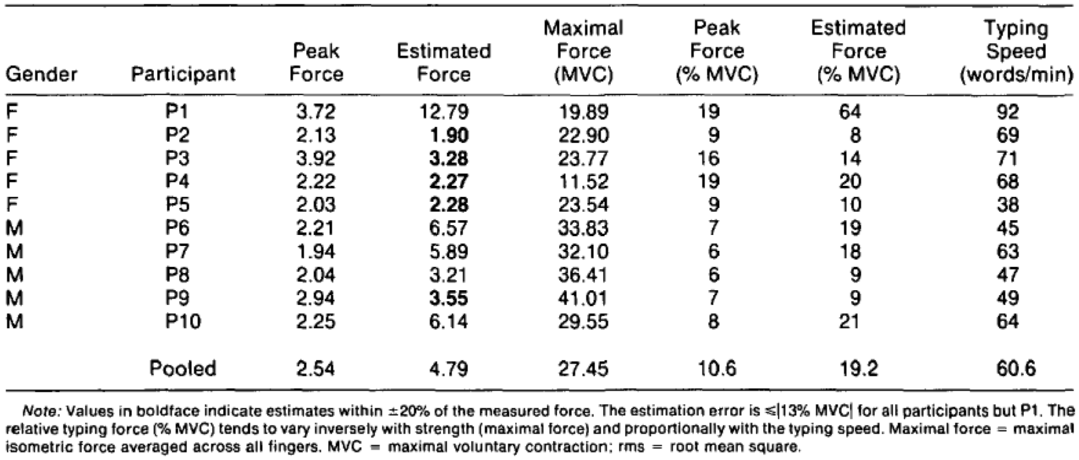
4.10 Estimates of Keyboard Reaction Force for a Keyboard Typing Task

Pain and impairment of the upper limb are often attributed to disability and compensation among occupational keyboard users (Martin *et al.*, 1996). Muscular fatigue, ischemia, and tendon and nerve compression are principal mechanisms leading to related upper limb disorders (Faucett & Rempel, 1994). The repetitive and sustained nature of typing task exertions is most often attributed as the primary risk factor for such disorders (Martin *et al.*, 1996).

Police-specific keyboard data entry ranges from a few keystrokes per hour to highly repetitive data entry depending on the division in which a given officer works. Based on in-car observation, traffic division officers perform infrequent, short intervals of moderate keystroke tasks, but primarily use the keyboard as a command-response tool at a rate of a few keystrokes per hour. Time-history analysis of in-car digital video will yield mean police keyboard typing task duration.

In creating the police work environment *in vitro* and using digital human modeling software, a peak keystroke force estimate is needed to simulate the required exertion in traffic division police typing task set. Armstrong, Foulke, Martin, Gerson, and Rempel (1994) had observed that applied keystroke force was 2.5 to 3.9 times greater than the force required to depress the key (key switch make force). Martin *et al.* (1996) expanded on this work with an investigation of methods to assess finger forces and muscle activity during a keyboard typing task and the relationship between keyboard reaction forces and flexor EMG during a typing task. Trials of a pangramic text typing task were performed on a keyboard with an average keystroke or "make" force of 0.47N. Average peak keystroke force was 2.59N, which represents 9% MVC of the subject pool (Table 4). To simulate required police exertions, a 2.59N keystroke force acting at the hand is appropriate. It is recognized that this does not maximize the fidelity of the task simulation, but the complex hand and wrist modeling required to achieve that is beyond the scope of this project.

Table 4: Estimates of peak force using base to peak RMS EMG average of all fingers of each participant and typing speed.



Gender	Participant	Peak Force	Estimated Force	Maximal Force (MVC)	Peak Force (% MVC)	Estimated Force (% MVC)	Typing Speed (words/min)
F	P1	3.72	12.79	19.89	19	64	92
F	P2	2.13	**1.90**	22.90	9	8	69
F	P3	3.92	**3.28**	23.77	16	14	71
F	P4	2.22	**2.27**	11.52	19	20	68
F	P5	2.03	**2.28**	23.54	9	10	38
M	P6	2.21	6.57	33.83	7	19	45
M	P7	1.94	5.89	32.10	6	18	63
M	P8	2.04	3.21	36.41	6	9	47
M	P9	2.94	**3.55**	41.01	7	9	49
M	P10	2.25	6.14	29.55	8	21	64
	Pooled	2.54	4.79	27.45	10.6	19.2	60.6

Note: Values in boldface indicate estimates within ±20% of the measured force. The estimation error is ≤|13% MVC| for all participants but P1. The relative typing force (% MVC) tends to vary inversely with strength (maximal force) and proportionally with the typing speed. Maximal force = maximal isometric force averaged across all fingers. MVC = maximal voluntary contraction; rms = root mean square.

*from Martin, Armstrong, Foulke, Natarajan, Klinenberg, Serina, Rempel (1996)**.**

5.0 Methods

The methods are described for two distinct project aspects: 1) a field investigation of mobile police officer activity postures, and 2) a laboratory investigation testing these configurations in a simulated police patrol session.

5.1 Field Quantification of Physical Exposures in Police Cruiser Operators

The field quantification was a mobile police officer surveillance study in which current-duty officers were monitored during the course of a working day using a digital video collection system to identify activities performed and postures assumed by drivers.

5.1.1 Participants

Ten (10) traffic division officers (8 male; 2 female) volunteered for this study. Participants were in good general physical health and provided written informed participatory and video consent (Appendix A). Mean participant age and stature were 37.5 (± 4.3) years and 179.1 (± 12.3) cm, respectively.

5.1.2 Posture and Load Exposure Assessment Survey

Officers completed a posture and load exposure assessment survey at the beginning of their shift during which digital video was collected (Appendix B). There were no exclusion criteria for completion of the survey. This subjective perceived discomfort questionnaire provided officers an opportunity to evaluate any pain, immobility and impracticality with equipment interfaces that they experienced. The survey had three sections: (1) 27 questions regarding the automotive seating environment,

(2) 20 questions regarding body discomfort, and (3) an open section for additional comments and suggestions. This survey was adapted from similar, validated assessments done by Mergl *et al.* (2005) and Donnelly, Callaghan and Durkin (*in press*). Modifications to the survey were omission of questions regarding automotive upholstery, generalization of questions regarding the driver seat surfaces, inclusion of questions regarding discomfort caused by the steering wheel, and addition of an open section for suggested improvements of equipment locations. All responses were given on a 100mm visual analog scale, with 0mm representing "No discomfort" and 100mm representing "Extreme discomfort" (Figure 10).

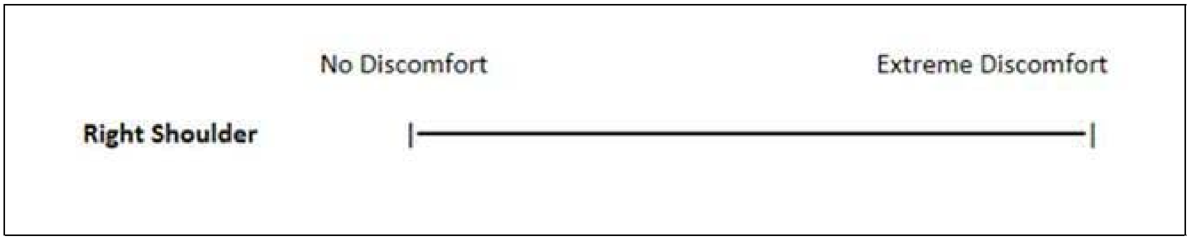


Figure 10: Sample 100mm visual analog scale for participant discomfort in the right shoulder. An identical scale was used to measure low back discomfort after each typing and driving task in the simulated police patrol session.

5.1.3 Video Collection System Components

A laptop-based video collection system was assembled and mounted to the interior of a Ford Crown Victoria police cruiser. The system consisted of three components: 1) a 3.6mm, 0.1 LUX bullet camera (Defender Security, Centerville, OH, USA) which was mounted on the passenger side of the roll cage, approximately 10° posterior to the driver's seated frontal plane (Figure 11), 2) a laptop computer anchored in a protective housing and secured on the passenger side floor of the vehicle, and 3) a USB device (Sunplus SPC506A Video Capture, Bronzepoint Security Products, Belleville, IL, USA). Digital video was captured at 20Hz using Windows Movie Maker collection software. Audio collection was disabled for all trials.

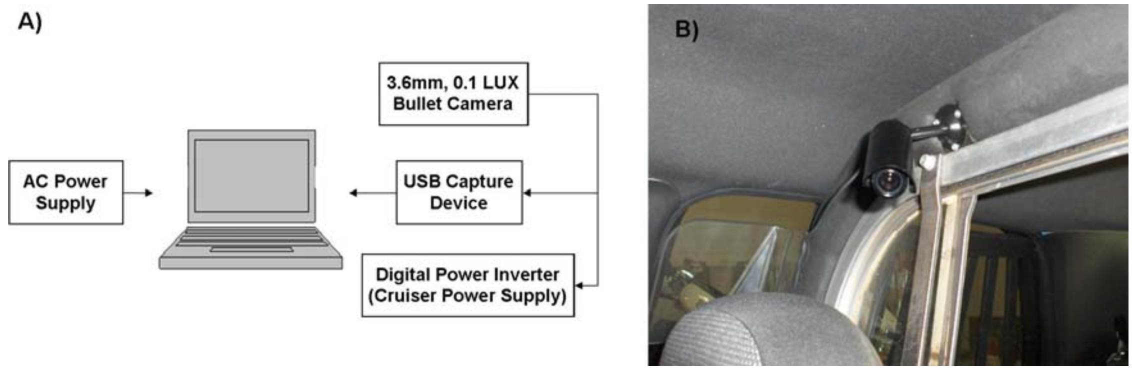


Figure 11: Video collection system **a)** system components, **b)** camera placement on the passenger-side roll cage of police cruiser.

5.1.4 Video Data Collection and Analysis

Continuous digital video was captured for single occupant police cruiser daytime shifts between 5.5 and 9.5 hours in duration. An experimenter initiated operation of the video collection equipment and officers were instructed to perform their daily task set as they normally would. Video was pre-screened to identify a set of common driver activities and yielded ten possible driver activity postures (Table 5).

Table 5: REACT driver activity posture selections

Activity Posture	Description
1	Right-handed MDT use
2	Two-handed MDT use
3	Two-handed driving
4	On-paper documentation
5	Left-handed driving (right upper limb relaxed)
6	Forward right arm reach
7	Lateral right arm reach
8	Traffic observation
9	Vehicle entry/exit
10	Out of vehicle

*MDT is mobile data terminal

Full shift video files (.wmv) were down-sampled from 20Hz to 1Hz. This minimized file size and processing duration while maintaining video integrity and capture of whole body activity posture details.

Each full shift video collection was

analyzed using REACT (Regional Enforcement Activity Characterization Tool) custom software developed at the University of Waterloo using MATLAB R2008a (Mathworks, Natick, MA). Video was loaded into REACT graphical user interface (Figure 12) and officers were activity matched for each frame of digital video. Video frames were matched to one of the ten pre-determined driver activities. The total number of frames identified in each of the activity postures yielded cumulative time spent in each activity, in seconds. These cumulative totals were used to calculate the percentage time in each activity posture for the entire shift (T_{net}, Equation 1), percentage of in-car time in each activity posture (excluding time outside of vehicle) (T_{in}, Equation 2), and the percentage of time in each activity after initial vehicle entry (T_{entry}, Equation 3).

$$T_{net}(p) = \frac{\sum_{i=1}^{N} \frac{t_i(p)}{t_{total,i}}}{N} \tag{1}$$

$$T_{in}(p) = \frac{\sum_{i=1}^{N} \frac{t_i(p)}{t_{total,i} - t_i(10)}}{N} \tag{2}$$

$$T_{entry}(p) = \frac{\sum_{i=1}^{N} \frac{t_i(p)}{t_{total,i} - a_i}}{N} \tag{3}$$

where, $t(p)$ is cumulative time in posture p
N is number of participants
t_{total} is total shift time
a is time before initial vehicle entry

Group means and standard deviations were calculated for percentage time in each activity for the entire shift, percentage of in-car time in each activity, and percentage of time in each activity after initial vehicle entry.

The activity identification produced a time-history of driver activities that defines officer order, frequency and duration in each activity posture (Figure 13). Time-history data was analyzed with custom software developed in Matlab R2008a (Mathworks, Natick, MA). The duration of each group of consecutive video frames in activities 1 (right-handed MDT use) and 2 (two-handed MDT use) were determined and mean keyboard typing task duration was calculated.

Regional Enforcement Activity Characterization Tool

by Colin D. McKinnon

[redacted]

Current Frame: 171 of 7200

File Name: Trial008_1Hz_part4(21601-28800).a

Position Count

1: 49
2: 44
3: 54
4: 65
5: 392
6: 87
7: 26
8: 71
9: 56
OUT: 5187

Figure 12: Regional Enforcement Activity Characterization Tool (REACT) graphical user interface for officer activity selection.

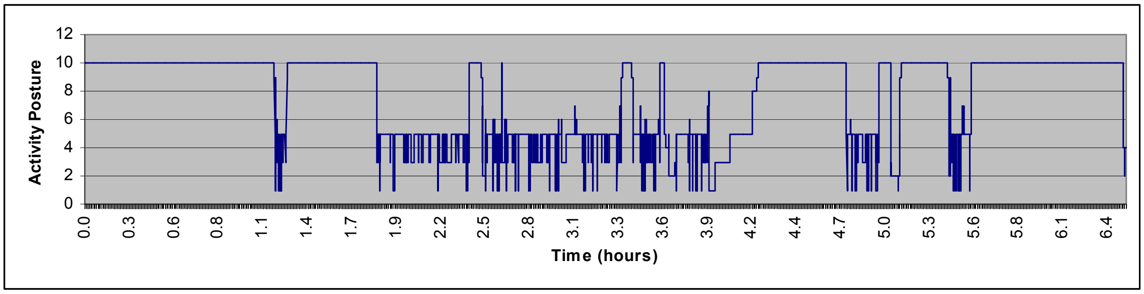


Figure 13: Sample time-history of police officer activity postures. *Note*: driver activity numerical values represent the postures indicated in Table 5.

5.2 The Evaluation of Mobile Data Terminal Location During a Simulated Police Patrol Task Set

Two separate 1-hour simulated police patrol testing sessions were performed in a laboratory driving simulator setup (Figure 14), in which nine channels of bipolar surface EMG, 21 surface-placed markers for motion tracking, seat pan pressure mapping, lumbar accelerations, and ratings of perceived discomfort were recorded. Participants used a driver seat equipped with an active lumbar support (ALS) system for one session and a standard Ford Crown Victoria driver seat for the other with seat type order randomized.

Figure 14: Experimental driving simulator setup and laboratory environment.

For the duration of each testing session, participants were seated in a self-selected simulated driving position, facing forward (Figure 15a and 15b). Seat forward-backward position was adjusted to the ‘most comfortable’ position by the participants prior to testing, and this position was then recorded and fixed for the duration of the session. The selected seat position was independent between testing sessions. Lumbar support in each of the seats was self-selected prior to the simulated patrol and could be modified by the participant at any time during the session. Time and nature of any lumbar support adjustments were recorded. Participants performed maximum voluntary contractions for the nine collected muscles for EMG normalization. Participants then performed a 1-hour simulated police patrol session consisting of 15-minute driving and 1-minute typing tasks. For the duration of each testing session, participants were equipped with police body armour and duty belt containing a personal radio (0.65kg), a pepper spray canister (0.08kg), a flashlight (0.52kg), a retractable assault baton (0.57kg), a pair of handcuffs (0.26kg), a fully loaded firearm (0.67kg), and two fully loaded ammunition magazines (1.0kg). Net mass of the loaded duty belt was 4.75kg.

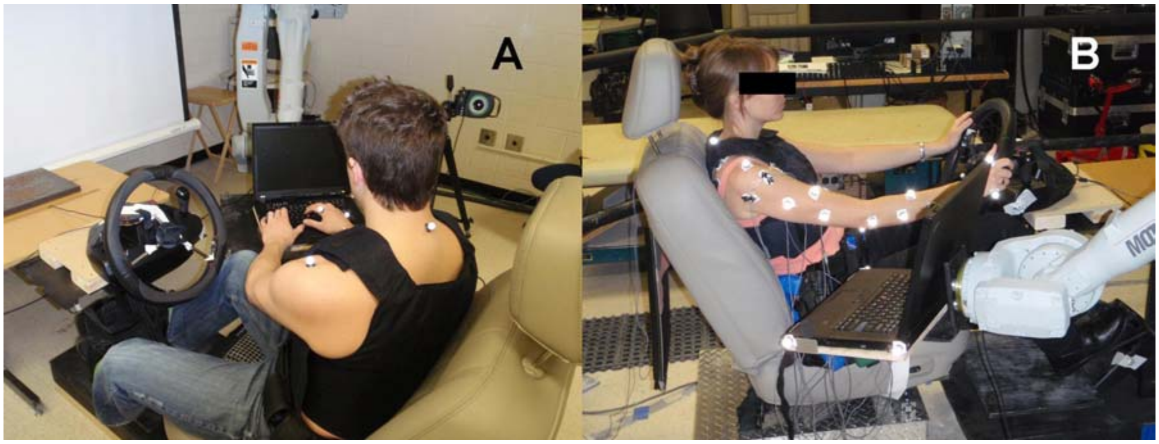


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Figure 15: Participant posture for a) simulated typing task and b) simulated driving task.

5.2.1 Typing Task

Participants performed a simulated mobile police typing task intermittently during each testing session. The task consisted of two integrated elements: (1) a command-response task to simulate dispatch communication and (2) a facial description typing task to simulate offender physical description recognition. For the command-response element, participants performed a series of single word or short sentence responses to on-screen questions or instructions. For the facial description element, participants typed a simple description of a facial image that appeared on the screen. Each typing task element was 30-seconds in duration. The simulated mobile police typing task software was a custom application developed in Matlab 2008a. Typing task elements were based on reported MDT function usage distribution (Hampton & Langham, 2005) and verified by observed activity descriptions of traffic division constables.

5.2.2 Simulated Police Patrol

Each simulated police patrol session consisted of three 15-minute simulated highway driving tasks that were each followed by a set of five 1-minute simulated mobile police typing tasks (Figure 16). Simulated highway driving was performed in a custom driving simulator setup. The driving course consisted of straight road with minor bends, and driving speed was maintained at 100km/h. Typing tasks were performed at each of five randomly ordered MDT locations. Participants were instructed to perform typing tasks in a natural posture with either one or two hands. The order of the two elements for each typing task was randomized for each trial.

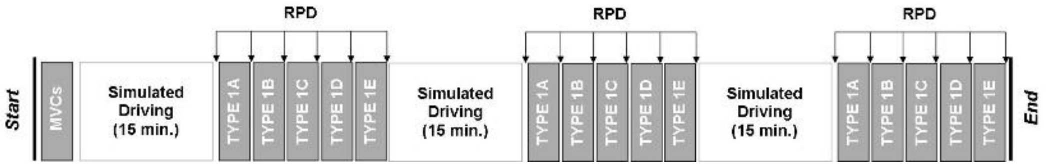


Figure 16: Study design – participants performed three sets of five 1-minute typing tasks each separated by 15-minutes of simulated driving.

5.2.3 Participants

Twenty (10 male; 10 female) University of Waterloo undergraduate and/or graduate students aged 18-28 volunteered for this study. Participants were recruited via poster and verbal recruitment. Participants were in good general physical health with no history of shoulder or lower back injury/pain within the last 12 months. Participants provided written informed consent (Appendix C). Participants were stature-matched across genders in an attempt to get an experimental representative of the general population. Participant age, stature and body mass information are shown in Table 6.

Table 6: Participant Information.

	Height (cm)	**Body Mass (kg)**	**Age**
Max.	195.5	118.0	28.0
Min.	156.8	56.8	18.0
Mean.	175.6	79.2	23.3

5.2.4 Surface Electromyography

Nine bipolar surface electrodes were placed on the skin over 9 muscles and muscle-elements surrounding the right shoulder. One electrode was placed on the skin superficial to the right clavicle as a reference electrode. Skin was prepared by shaving the electrode site with a new disposable razor and wiped with isopropyl alcohol *as per* Zipp (1982). Fixed distance (2cm) dual surface electrodes (Noraxon USA, Inc., Ag/AgCl; IE resistance: 200kΩ, USA) were placed over *m.* pectoralis major (clavicular insertion), *m.* upper trapezius, *m.* anterior deltoid, *m.* middle deltoid, *m.* posterior deltoid, *m.* biceps brachii, *m.* triceps brachii, *m.* infraspinatus and *m.* supraspinatus. Surface electrodes placement sites and test contractions are described in Table 7.

Table 7: Experimental Surface Electrode Placement Instructions

Surface Electrodes	**Placement Location**
Pectoralis Major (clavicular insertion)	*Electrode Placement:* Between sternoclavicular joint and the caracoidus process, 2 cm below the clavicle (on an angle down and laterally) *Test Contraction:* Shoulder abducted to 90º, horizontally adduct & flex shoulder. Resist (from above) proximal to elbow joint in a downward and outward direction.
Upper Trapezius	*Electrode Placement:* 2/3 on the line between the trigonum spinae and the 8th thoracic vertebrae, 4 cm from muscle edge, at approximately a 55° oblique angle *Test Contraction:* Prone: shoulder abduction at 90º with elbow extended, thumb down
Anterior Deltoid	*Electrode Placement:* 2-4 cm below the clavicle, parallel to muscle fibers *Test Contraction:* Sitting: Forward flexion at 90°
Middle Deltoid	*Electrode Placement:* 3 cm below the lateral rim of the acromion, over muscle lass, parallel to muscle fibers *Test Contraction:* Sitting: abduct the arm to 90° (elbow extended, thumb forward)
Posterior Deltoid	*Electrode Placement:* 2 cm below lateral border of scapular spine, oblique angle toward arm (parallel to muscle fibers) *Test Contraction:* Prone: Extension when arm is abducted to 90º and externally rotated (thumb forward)
Biceps brachii	*Electrode Placement:* Above the centre of the muscle, parallel to the long axis *Test Contraction:* Sitting: Forearm flexion (resistance increases EMG)
Triceps Brachii	*Electrode Placement:* On the posterior portion of the upper arm, located medially *Test Contraction:* Supine: shoulder and elbow flexed to 90º; forearm extension against resistance
Infraspinatus	*Electrode Placement*: Parallel to spine of scapulae, approximately 4 cm below, over the infrascapular fossa *Test Contraction:* Sitting: elbow bent to 90°, external rotation of arm
Supraspinatus	*Electrode Placement:* Midpoint and 2 finger-breadths anterior to scapular spine *Test Contraction:* Side-lying: abduct shoulder to 5° with elbow extended (thumb forward); abduct against resistance

Based on Brookham (2008) and Delagi & Pegotto (1980)

The nine channels of muscle generated potentials were collected with a 16-channel Noraxon Telemyo 2400T G2 Telemetry electromyography system (Noraxon U.S.A. Inc., Scottsdale, AZ). System leads were equipped with a 1st order high-pass filter (10 Hz +/- 10% cut-off). Input channels had 10-500Hz analog band pass filters. EMG active lead specifications included a differential amplifier common mode rejection ratio of >100 dB and input impedance of >100 mΩ. The gain was set at 1000. The transmitter data acquisition system has 16-bit resolution on all analog inputs. The system was limited to 1500Hz and 3000Hz sample rates (f_s). Given a surface EMG bandwidth of 10-500 Hz (Hagberg & Hagberg, 1989), a 1500 Hz sample rate was used in order to satisfy the Nyquist theorem ($f_s = 2n + 1$, where n is the highest frequency content of the collected signal) . The system receiver converted the digital telemetry data read from the surface electrodes to analog output signals. Output signals were transferred to a personal computer for subsequent recording with Vicon Nexus 1.2 software (Vicon Motion Systems Ltd., Los Angeles, CA).

5.2.4.1 Maximum Voluntary Contraction (MVC) Collection

Electromyography of each recorded muscle for testing trials was normalized to percentage of the maximum voluntary contraction (MVC) EMG amplitude for relative signal comparison between individual muscles and between subjects (MVC exertions are described in Table 7). Subjects performed two isometric MVC contractions for each of the 9 recorded muscles, separated by two minutes of rest to eliminate fatigue effects (*as per* DeLuca, 1997). Subjects were asked to ramp up to their MVC within a six second collection period, reaching peak force production after two seconds. The peaks of the two linear enveloped trials were averaged and used as the MVC amplitude for each muscle.

5.2.5 Motion Tracking System

To act as input for the SLAM biomechanical model (Dickerson, Chaffin & Hughes, 2007), participant kinematics were recorded throughout all tasks. This information yielded specific torso and upper limb positions and orientations for driving and typing tasks, and were used to estimate dynamic joint moments and forces. The Vicon MX motion capture system (Vicon Motion Systems Ltd., Los Angeles, CA) was used to record upper limb and torso kinematic data. Seventeen reflective markers were placed on each participant at external bony landmarks and segment tracking triad locations, and four markers were placed on the mobile data terminal (Table 8). Eight Vicon MX20+ (2.0 MP) cameras surrounded the collection space and tracked the motion of the reflective markers throughout the task set. Motion and position data were collected with Vicon Nexus 1.2 software. Each task collection was recorded synchronously with the nine channels of surface electromyography.

Table 8: Motion tracking reflective marker positions

Marker	Location
1	5th metacarpal phalangeal joint
2	2nd metacarpal phalangeal joint
3	ulnar styloid
4	radial styloid
5	lateral epicondyle
6	medial epicondyle
7	right acromion
8	left acromion
9	C7 spinous process
10	suprasternal notch
11	xyphoid process

12	arm triad I
13	arm triad II
14	arm triad III
15	forearm triad I
16	forearm triad II
17	forearm triad III
18	mobile data terminal I
19	mobile data terminal II
20	mobile data terminal III
21	mobile data terminal IV

Note: Arm Triad I, II and III form a triangular segment tracking cluster on the right upper arm.

Forearm Triad I, II and III form a triangular segment tracking cluster on the right forearm.

All markers are on the right side of the body unless otherwise indicated.

5.2.6 Ratings of Perceived Discomfort

Ratings of perceived discomfort (RPD) were recorded after each driving and typing task was performed during the session. The RPD was rated on a visual-analog scale 100mm long (Appendix D). Participants rated both their right upper limb and lower back discomfort after the completed task, with 0mm being ‘no discomfort’ and 100mm being ‘extreme discomfort’.

5.2.7 Laboratory Setup and Components

The simulator setup followed that of Durkin *et al.*, 2006. The simulator included a car seat, dashboard, steering wheel, brake and gas pedals, mobile data terminal (MDT) and a viewing monitor (Figure 17). The driving simulation software was STISIM Drive (Systems Technology Inc., Hawthorne, CA, USA). The steering wheel was a standard Ford Crown Victoria wheel, and gas/brake pedals were a commercial product compatible with the driving simulation software. A representative mobile data terminal was fixed on a Motoman NX100 robotic arm (Motoman, West Carrollton, OH, USA), allowing six degree of freedom adjustment of location and orientation relative to the driver and seat. Simulator and mobile data terminal component locations were setup according to standard dimensions of a Ford Crown Victoria Police Cruiser.

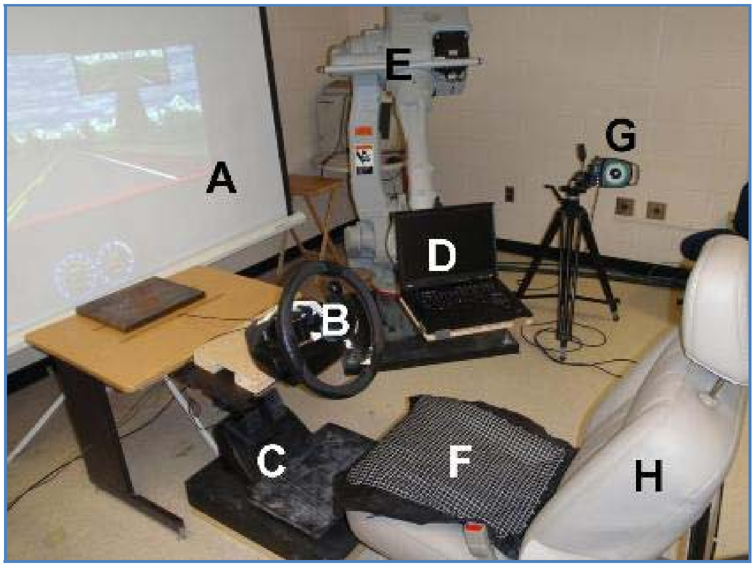


Figure 17: Driving simulator and data collection components. A) Viewing screen, B) steering wheel, C) gas and brake pedal assembly, D) mobile data terminal, E) Motoman NX100 robotic arm, F) Seat pressure mat, G) Vicon MX20+ Camera, H) Ford Crown Victoria driver seat.

5.2.7.1 Driver Seats

Participants used a modified driver seat equipped with an active lumbar support (ALS) system for one session and a standard Ford Crown Victoria driver seat for the other. The Crown Victoria driver seat allowed for only anteroposterior lumbar support adjustment. The modified ALS seat was a prototype that, in addition to manual anterior-posterior and superior-inferior lumbar support adjustment, produced cyclic anterior-posterior-superior-inferior excursions of the lumbar support with a cycle time of 20 seconds. The system ran for 10 minutes after which the driver was required to re-initiate the mechanism. The modified ALS seat contained a shortened seat pan and foam structure modifications to accommodate the police duty belt and provide active support through interaction with the police protective vest.

5.2.7.2 Mobile Data Terminal (MDT)

Typing tasks were performed at one of five randomly ordered mobile data terminal locations. Locations were numerically classified as location 2-6 accordingly to robotic arm naming conventions. Four locations (location 2-5) were fixed relative to the simulated cruiser environment (Figure 18), and one location (location 6) was self-selected by participants as the ‘most comfortable’ location. The self-selected MDT location was chosen prior to testing sessions at the time of seat position selection. The only restriction placed on location self-selection was that it did not make contact with any other aspects of the simulated cruiser environment. The self-selected location was independently chosen for each testing session. The self-selected location was highly variable both across participants and between seat types (Table 9), however, mean location was similar to the current location (Figure 19). Mean self-selected location was within 6.0cm of the current location in the anterior-posterior, medial-lateral, and superior-inferior directions for both driver seat types (Table 9). Because driver seat position was adjustable, mobile data terminal locations are expressed relative to a fixed point, the front right mounting bolt of the driver seat (Table 10).

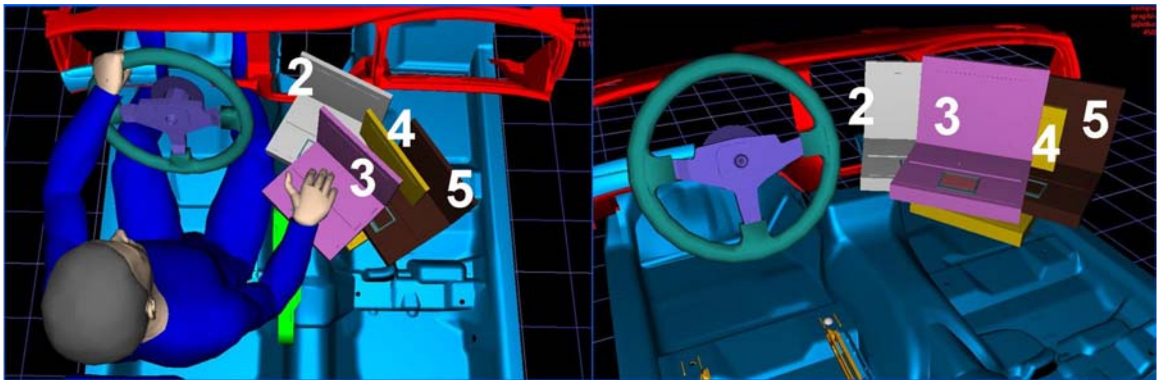


Figure 18: Four mobile data terminal locations fixed relative to simulated cruiser environment. Locations 2, 3 and 4 were developed in digital human modeling software to minimize an upper limb loading measure in three parallel planes.

Table 9: Mean and standard deviation of distance between current and self-selected MDT location. Positive values in the X and Y directions indicate that the self-selected MDT location is closer to the driver, and positive Z values indicate the self-selected location is below the current location. ALS is the active lumbar support driver seat; CV is the Crown Victoria driver seat.

		distance between locations (cm)		
		X (anterior-posterior)	**Y (superior-inferior)**	**Z (medial-lateral)**
ALS	mean	5.46	-3.92	1.65
	st. dev.	4.29	5.29	2.86
CV	mean	1.51	-1.19	0.84
	st. dev.	8.54	10.89	3.50

Table 10: Fixed MDT locations relative to the front right driver seat mounting bolt. Positive X direction is posterior; positive Y direction is superior; positive Z direction is right (towards passenger seat).

	Distance (cm)			
MDT Location Index	X	Y	Z	Net scalar distance
2	1.45	45.93	24.40	52.03
3	21.51	52.20	24.40	61.51
4	16.64	40.95	34.16	55.87
5	21.51	45.93	44.98	67.79

Fixed locations 3, 4 and 5 (Figure 18) were determined using Jack digital human modeling software (Siemens PLM Software, Plano, TX, USA). Computer-aided design (CAD) objects were acquired and modified for a representative mobile data terminal and Ford Crown Victoria police cruiser. A 95th percentile male digital human operator manikin was inserted in the virtual environment and visually posture matched to previously collected digital video data. A reach envelope for the manikin was determined, and an 11.0cm by 11.0cm grid was formed within it, aligned with the sagittal plane of the manikin. The tip of the 3rd digit on the right hand of the manikin was positioned at each intersection point in the grid in the one-handed typing posture. A 2.59N reactive finger force was applied at the point of finger-keyboard contact, which represents the average keystroke force for a keyboard typing task (Martin *et al.*, 1996). The summation of elbow extension, right shoulder abduction/adduction, right shoulder flexion/extension, and right shoulder internal/external rotation moments was calculated using the Static Strength Prediction tool within the software. The intersection point in each anteroposterior vertical plane which minimized this total moment value was identified (Figure 20).Three of these locations were within the physical and safety constraints of the police cruiser and were chosen as keyboard centre locations 3, 4 and 5. Location 2 represents the most commonly used current MDT location. Participants were not informed of MDT location prior to or at the time of any of the typing tasks.

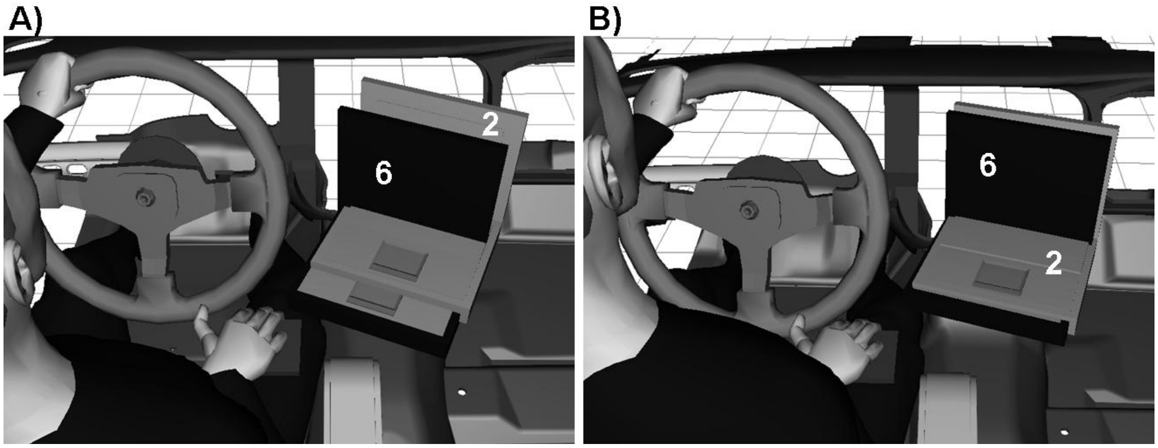


Figure 19: Mean self-selected (location 6) and current (location 2) MDT locations for both the a) Active Lumbar Support driver seat and b) Crown Victoria driver seat.

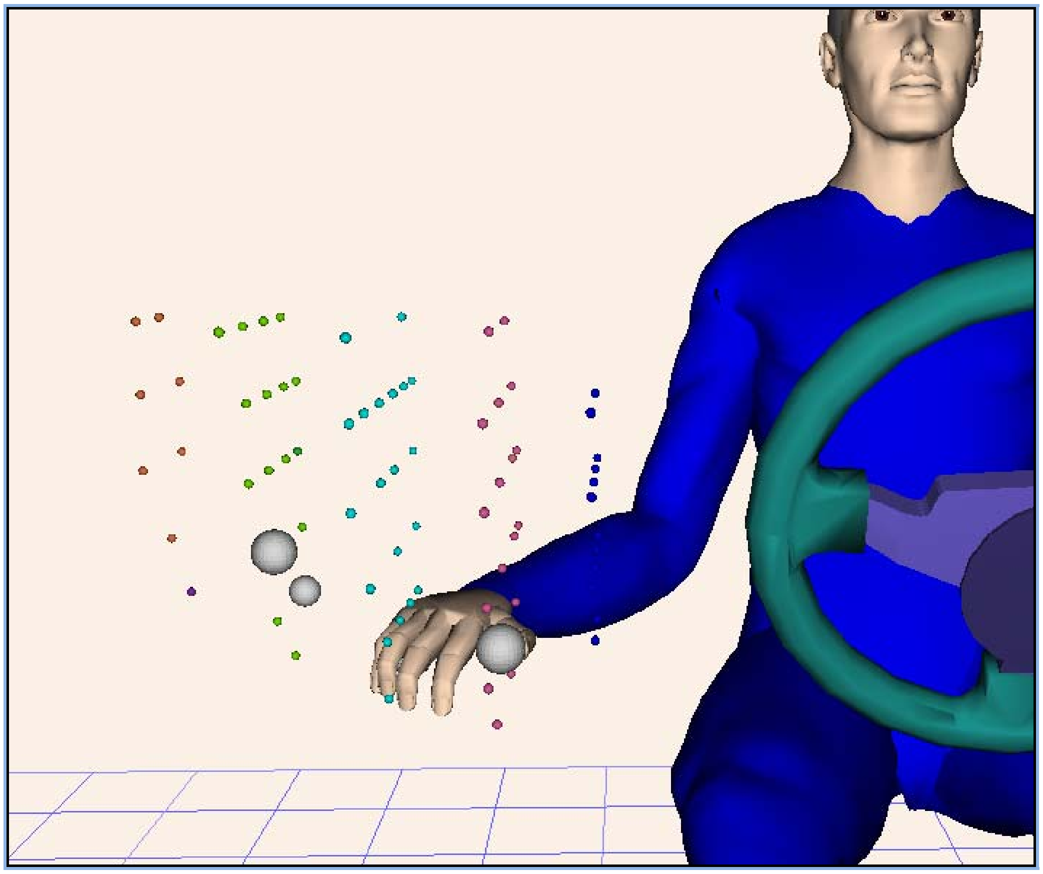


Figure 20: Evenly spaced planes of discrete points parallel to the sagittal plane of the driver.

5.2.8 Data analysis

All EMG data was processed using MATLAB 2008a (Mathworks, Natick, MA). The mean of two resting EMG trials in quiet lying was taken to represent the resting EMG signal for each muscle. All raw EMG was linear enveloped (full-wave rectified and filtered with a single-pass, 2nd order Butterworth filter) with a cutoff frequency of 2 Hz (Dark, Ginn & Halaki, 2007). Trial EMG recordings had resting bias removed and were normalized to individual muscle MVC values for comparison. Nine separate 4-way repeated measures ANOVAs (MDT location, seat type, typing task set, and gender) tested for significant trial mean muscle activity differences in each of the nine recorded muscles. A Tukey HSD post-hoc analysis was conducted when statistically significant differences were found. Statistical significance was considered at $\alpha = 0.05$.

Participant motion data gaps were pattern filled with Vicon Nexus 1.2 and Matlab 2008a software to remove any missing marker data. Motion files were input to the SLAM mathematical model (Dickerson, Chaffin & Hughes, 2007) using Matlab 2008a to generate time-series humeral elevation angles (3D angle between long axes of the torso and humerus), resultant dynamic right shoulder moment, and raw and normalized individual muscle force predictions (38 muscles and muscle elements). Raw muscle force predictions were summed to yield a model-based total predicted muscle force. Individual muscle EMG recordings were scaled to maximum producible force (F_{max}) for each muscle (Makhsous, 1999) (Appendix E) and summed to yield an EMG-based total muscle force. A 4-way repeated measures ANOVA (MDT location, seat type, typing task set, gender) was run for each of the six outcome measures (mean muscle activity, RPD, humeral elevation angle, resultant dynamic shoulder moment, model-based total muscle force, EMG-based total muscle force) and tested for significant main and interaction effects. A Tukey HSD post-hoc analysis was conducted when statistically significant differences were found. Statistical significance was considered at α = 0.05.

Outcome measure agreement was evaluated with an agreement matrix (example in Table 11). Within seat type rankings across mobile data terminal locations were determined for six outcome measures: (1) shoulder rating of perceived discomfort, (2) low back rating of perceived discomfort, (3) mean resultant dynamic shoulder moment, (4) mean humeral elevation angle, (5) EMG-based total empirical muscle force, and (6) model-based total predicted muscle force. The sample mean at each MDT location (within seat type) was calculated and ranked. The MDT location with the lowest level for a given outcome was ranked as 1 and other outcome measures were subsequently ranked based on identified statistically significant differences. Each of the six outcome measures were evenly weighted to calculate group average ranks across outcome measures (Equation 4).

$$\text{location rank mean} = \frac{\sum_{i=1}^{N} \text{rank}(\text{measure}_i)}{\text{N}} \tag{4}$$

Table 11: Sample outcome measure agreement matrix. RPD is rating of perceived discomfort.

	Outcome Measure Rank				
Outcome Measure	**Location 2**	**Location 3**	**Location 4**	**Location 5**	**Location 6**
Shoulder RPD	2	4	3	5	1
Low Back RPD	2	3	4	5	1
Mean Elevation Angle	2	5	4	3	1
Mean Resultant Dynamic Shoulder Moment	4	2	1	5	3
Muscle Activity Total	3	4	2	5	1
Total Predicted Muscle Force	1	4	5	2	3
Average Rank	2.33	3.67	3.17	4.17	1.67
Rank Order	**2**	**4**	**3**	**5**	**1**

6.0 Results

The results are described for the two distinct project aspects, which were a field investigation of mobile police officer activities and a laboratory investigation testing modified configurations in a simulated police patrol session.

6.1 Field Quantification of Physical Exposures in Police Cruiser Operators

Percentage time in each of the identified activities for the full shift of video collection, for activity in vehicle (out of vehicle activity omitted), and for activity after initial entry of the officer in the vehicle are presented in Tables 12, 13, and 14, respectively. For the full shift of video collection, the highest mean time spent in any one activity posture was 55.5 ± 13.4% of the shift out of the vehicle (Table 12). Time out of the vehicle occurred for various reasons, including roadside interaction due to traffic violations, attendance at Municipal Court meetings, equipment retrieval from the vehicle trunk, and meal breaks. The highest mean percentage time spent in an in-car activity posture was 50.3 ± 15.7% of time in-car driving with the left arm (right arm relaxed on arm rest) (Table 13).

On-paper documentation and MDT use represented the most time of in-car, non-driving activity postures. Completion of various daily logs on paper (on-paper documentation) consumed 20.8 ± 16.5% of the time. Mobile data terminal use (combined one-handed and two-handed) represented over 13.1% of time activities performed by officers.

To determine the length of driving tasks for a simulated patrol task set, mean initial driving duration prior to mobile data terminal use, vehicle exit, or on-paper documentation was calculated. Mean duration was 739.3 ± 734.5 frames of a 1Hz video collection (Table 15), which translates to 12 minutes, 19.3 seconds.

Slight variations existed for inter-participant individual joint postures, but whole-body activity postures consistently fit into one of the ten activity posture activities created in the REACT software tool. No frames were omitted from classification.

Table 12: Percentage time of full shift in each activity posture (*n* = 10).

Activity Posture	Mean Time (%)	Standard Deviation (%)	Rank
Officer out of vehicle	55.5	13.4	1
Left-handed driving (right-hand relaxed)	22.3	10.5	2
On-paper documentation	9.38	7.52	3
Right-handed MDT use	4.57	2.00	4
Two-handed driving	3.95	3.00	5
Vehicle entry/exit	1.28	0.49	6
Two-handed MDT use	1.23	1.06	7
Relaxed/Traffic watch	0.65	1.19	8
Right arm lateral reach	0.61	0.33	9
Right arm forward reach	0.53	0.36	10

Table 13: Percentage time of activity in vehicle in each activity posture with time out of vehicle omitted (*n* = 10).

Activity Posture	Mean Time (%)	Standard Deviation (%)	Rank
Left-handed driving (right-hand relaxed)	50.3	15.7	1
On-paper documentation	20.8	16.5	2
Right-handed MDT use	10.3	3.99	3
Two-handed driving	8.98	6.54	4
Vehicle entry/exit	3.09	1.29	5
Two-handed MDT use	2.78	1.81	6
Right arm lateral reach	1.49	0.81	7
Relaxed/Traffic watch	1.20	2.08	8
Right arm forward reach	1.12	0.60	9

Table 14: Percentage time of activity after initial vehicle entry in each activity posture ($n = 10$).

Activity Posture	Mean Time (%)	Standard Deviation (%)	Rank
Officer out of vehicle	50.4	16.7	1
Left-handed driving (right-hand relaxed)	24.7	11.6	2
On-paper documentation	10.4	8.64	3
Right-handed MDT use	5.01	2.14	4
Two-handed driving	4.57	3.78	5
Vehicle entry/exit	1.41	0.51	6
Two-handed MDT use	1.36	1.15	7
Relaxed/Traffic watch	0.81	1.56	8
Right arm lateral reach	0.68	0.38	9
Right arm forward reach	0.58	0.38	10

Table 15: Initial driving duration prior to mobile data terminal use, vehicle exit or on-paper documentation.

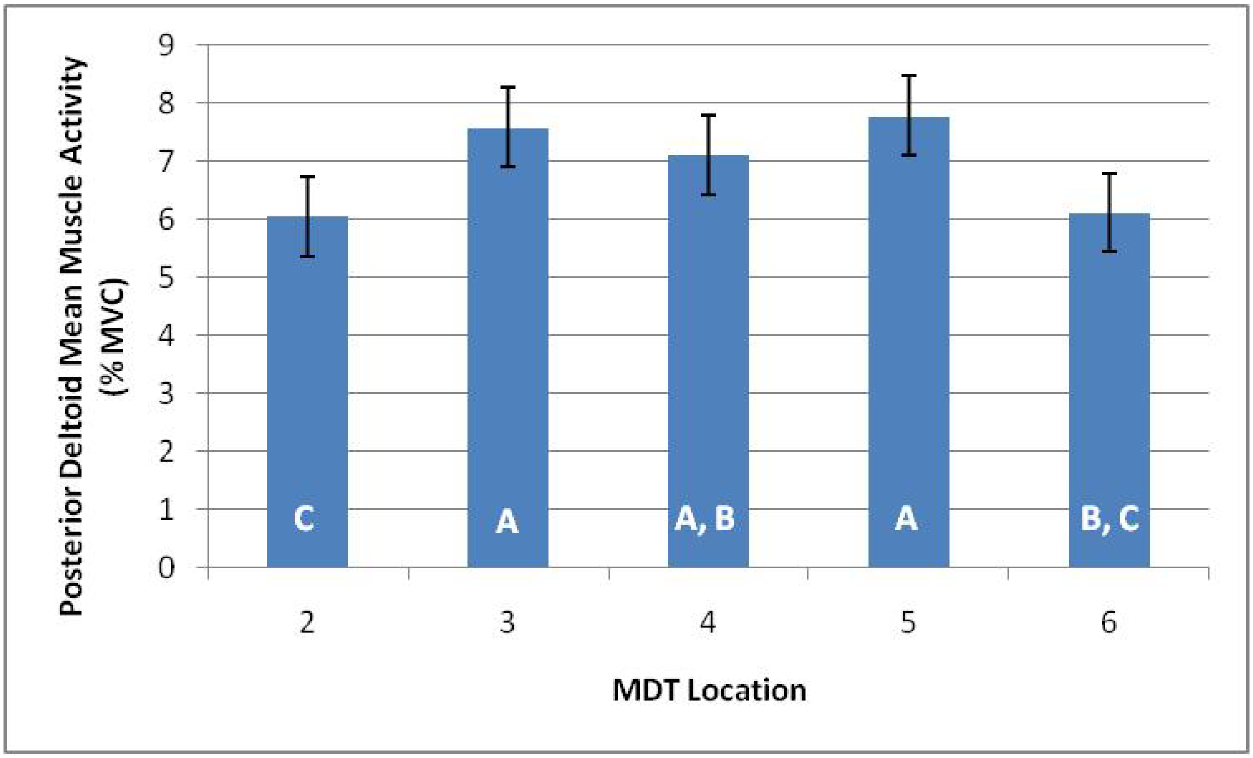
Trial	Duration (s)
1	2214
2	341
3	528
4	118
5	819
6	641
7	335
8	234
9	238
10	1925
Mean	739.3
S.D.	734.5

6.2 The Evaluation of Mobile Data Terminal Location During a Simulated Police Patrol Task Set

The results for the laboratory investigation of mobile data terminal location and driver seat type have are provided as a sub-section for each of six outcome measures and an agreement matrix, which incorporates all outcome measures.

6.2.1 Mean Muscle Activity Level

Mobile data terminal (MDT) location, driver seat type and gender each influenced the recorded mean muscle activity in one or more of the nine recorded muscles during simulated police typing tasks. All muscles that indicated significant differences had the highest muscle activity in locations 3 and 5, followed by location 4, and lowest in locations 2 and 6. Significant differences in mean muscle activity during the simulated police typing task were seen across mobile data terminal location for four of the nine recorded muscles: MDEL ($p = .0015$), PDEL ($p < .0001$), BICP ($p = .048$), and SUPR ($p < .0001$). Three levels of significance existed for PDEL and SUPR (Figure 21), whereas MDEL and BICP showed a location main effect, but only one level of significance upon post-hoc analysis.



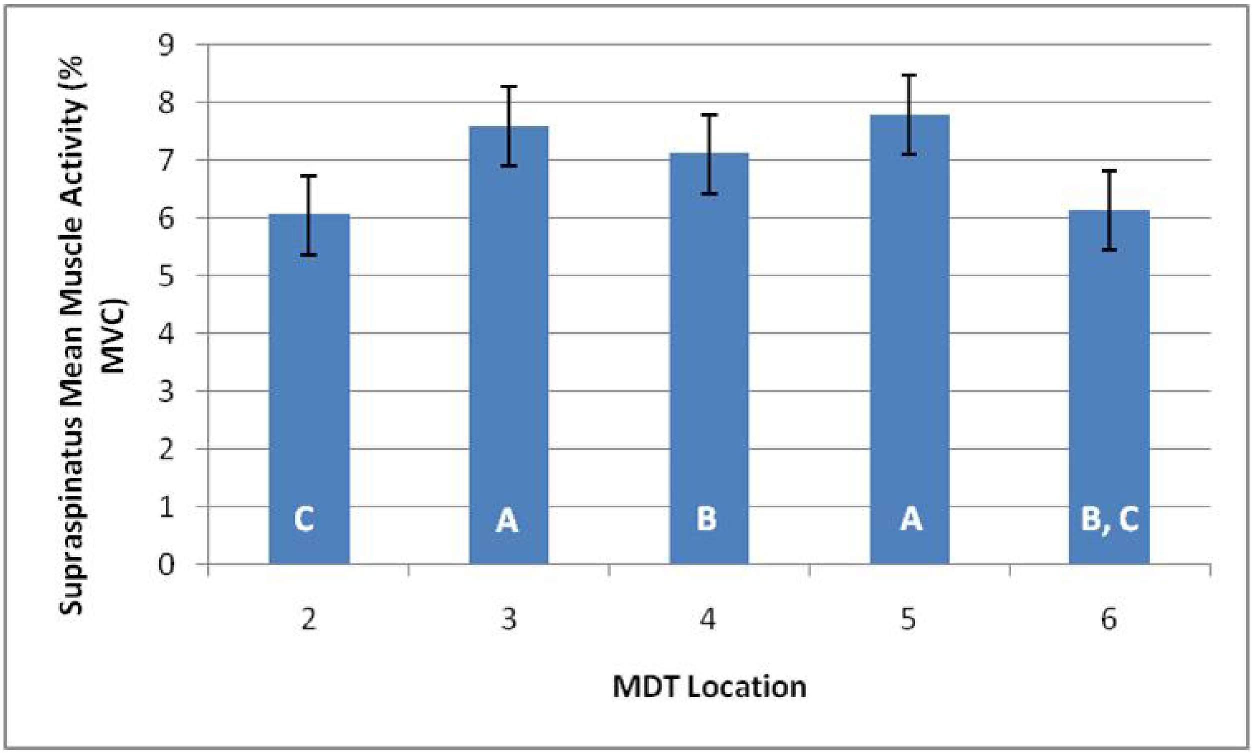


Figure 21: Mean muscle activity and significance level across MDT location for m. posterior deltoid and *m*. supraspinatus. Levels not separated by the same letter are significantly different.

Seat type elicited significant differences in mean muscle activity for simulated police typing tasks in six of the nine recorded muscles: PECC ($p = .0015$), ADEL ($p = .0117$), BICP ($p < .0001$), TRCP ($p < .0001$), INFR ($p = .0115$), and SUPR ($p = .0192$). Activity level was greater in the CV seat for all recorded muscles, except for UTRP and TRCP (Figure 22).

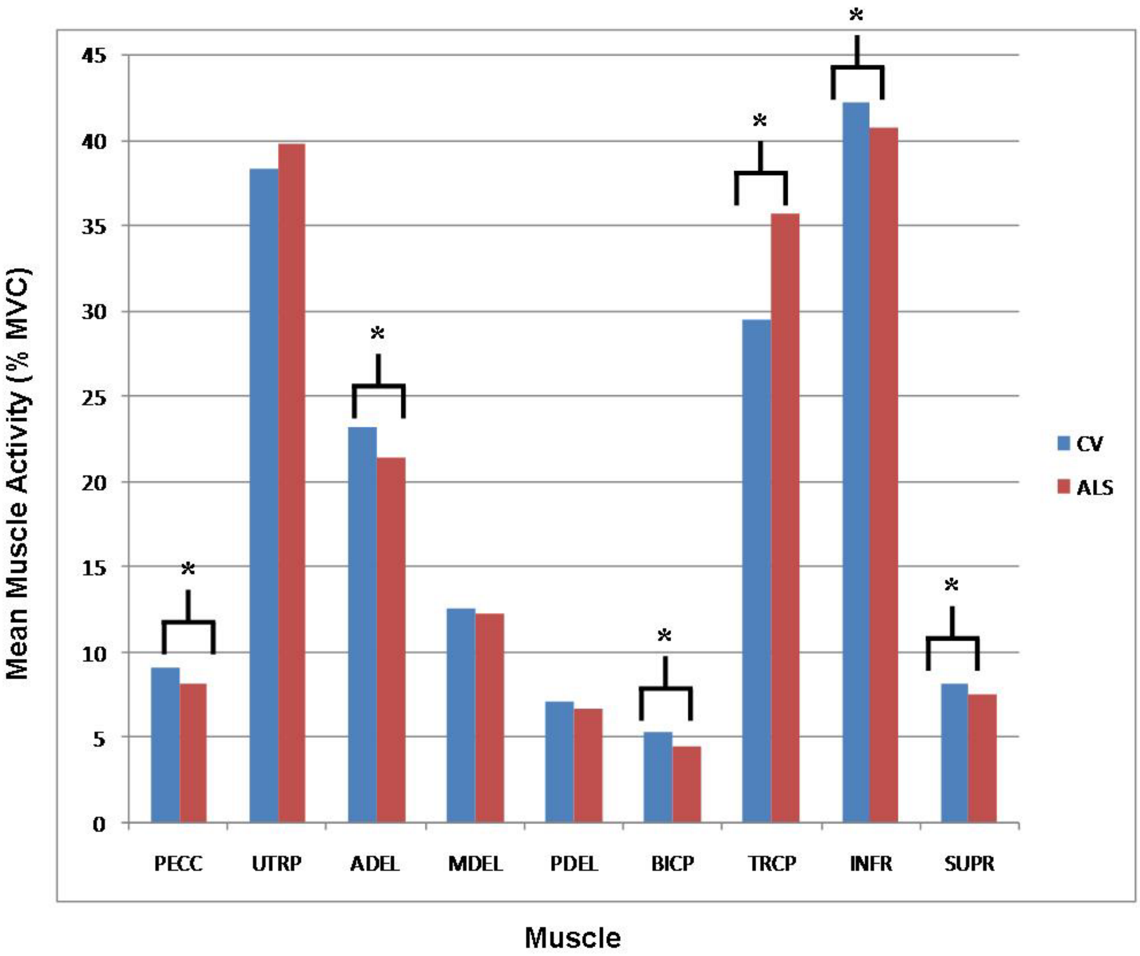


Figure 22: Mean muscle activity of all recorded muscles between seat types. CV and ALS refer to Crown Victoria and active lumbar support driver seats, respectively. Muscle abbreviations: pectoralis major (PECC), upper trapezius (UTRP), anterior deltoid (ADEL), middle deltoid (MDEL), posterior deltoid (PDEL), biceps brachii (BICP), triceps brachii (TRCP), infraspinatus (INFR), supraspinatus (SUPR). * indicates significant differences.

Gender differences existed in mean muscle activity for simulated police typing tasks in two of the nine recorded muscles: BICP (*p* = .0381) and TRCP (*p* = .0070). Activity level was greater in female participants for both of these muscles—6.3 %MVC (female) vs. 3.5 %MVC (male) for BICP; 41.0 %MVC (female), vs. 24.3 %MVC (male) for TRCP.

A significant seat type by gender interaction effect emerged for six of the nine recorded muscles: PECC (*p* = .0028), MDEL (*p* = .0003), BICP (*p* < .0001), TRCP (*p* =

.0010), INFR (*p* < .0001), SUPR (*p* < .0001). Trends and significance of this interaction varied across muscles (Figure 23). Mean muscle activities for all recorded muscles across MDT location and seat type are presented in Table 16-18.

Table 16: Mean and standard deviation of muscle activity for all recorded muscles across MDT location for active lumbar support (ALS) driver seat.

	MDT Location									
	2	s.d.	**3**	s.d.	**4**	s.d.	**5**	s.d.	**6**	s.d.
Pec. Major	8.58	4.50	8.19	4.40	7.97	4.53	8.20	4.55	8.14	4.48
Upper Trapezius	39.92	23.79	40.29	23.79	39.52	23.99	40.14	23.53	39.62	23.84
Ant. Deltoid	21.72	11.82	21.62	11.85	21.35	12.17	21.68	11.85	21.36	12.17
Mid. Deltoid	11.96	5.78	12.58	5.64	12.02	5.90	13.41	5.89	11.69	5.89
Post. Deltoid	6.17	4.82	7.15	4.58	6.74	4.49	7.52	5.24	6.03	3.95
Biceps Brachii	4.47	2.80	4.50	2.46	4.29	2.55	4.92	2.94	4.20	2.55
Triceps Brachii	35.98	15.12	35.92	15.03	35.68	15.44	35.98	15.14	35.34	15.70
Infrspinatus	40.46	14.96	41.75	14.21	39.91	15.47	41.50	14.31	40.15	15.52
Supraspinatus	6.23	3.19	9.05	6.12	7.13	3.66	9.22	4.82	6.31	3.06

Table 17: Mean and standard deviation of muscle activity for all recorded muscles across MDT location for Ford Crown Victoria (CV) driver seat.

	MDT Location									
	2	s.d.	**3**	s.d.	**4**	s.d.	**5**	s.d.	**6**	s.d.
Pec. Major	9.57	5.44	9.01	5.23	8.75	5.41	9.00	5.15	9.16	5.14
Upper Trapezius	38.09	26.45	38.71	25.94	37.88	26.95	38.82	25.81	38.48	25.93
Ant. Deltoid	23.13	10.67	23.10	10.34	22.82	10.90	23.44	10.27	23.62	10.84
Mid. Deltoid	11.45	5.57	13.50	5.97	12.56	6.02	13.75	5.94	11.78	5.51
Post. Deltoid	5.93	2.49	8.02	3.61	7.48	3.44	8.04	3.31	6.20	2.40
Biceps Brachii	5.14	4.13	5.56	4.26	5.10	4.13	5.72	4.52	5.06	3.93
Triceps Brachii	29.20	16.99	29.92	16.65	28.72	17.40	29.95	16.73	29.85	16.60
Infrspinatus	42.26	15.12	42.54	14.17	41.44	15.98	42.66	14.07	42.44	14.17
Supraspinatus	6.46	3.66	10.18	4.90	7.80	4.18	9.48	5.34	6.90	3.84

Table 18: Mean and standard deviation of muscle activity for accumulated data set.

	PECC	**UTRP**	**ADEL**	**MDEL**	**PDEL**	**BICP**	**TRCP**	**INFR**	**SUPR**
mean	8.66	39.15	22.38	12.47	6.93	4.90	32.66	41.51	7.88
s.d.	4.89	24.86	11.26	5.82	3.99	3.53	16.29	14.73	4.57

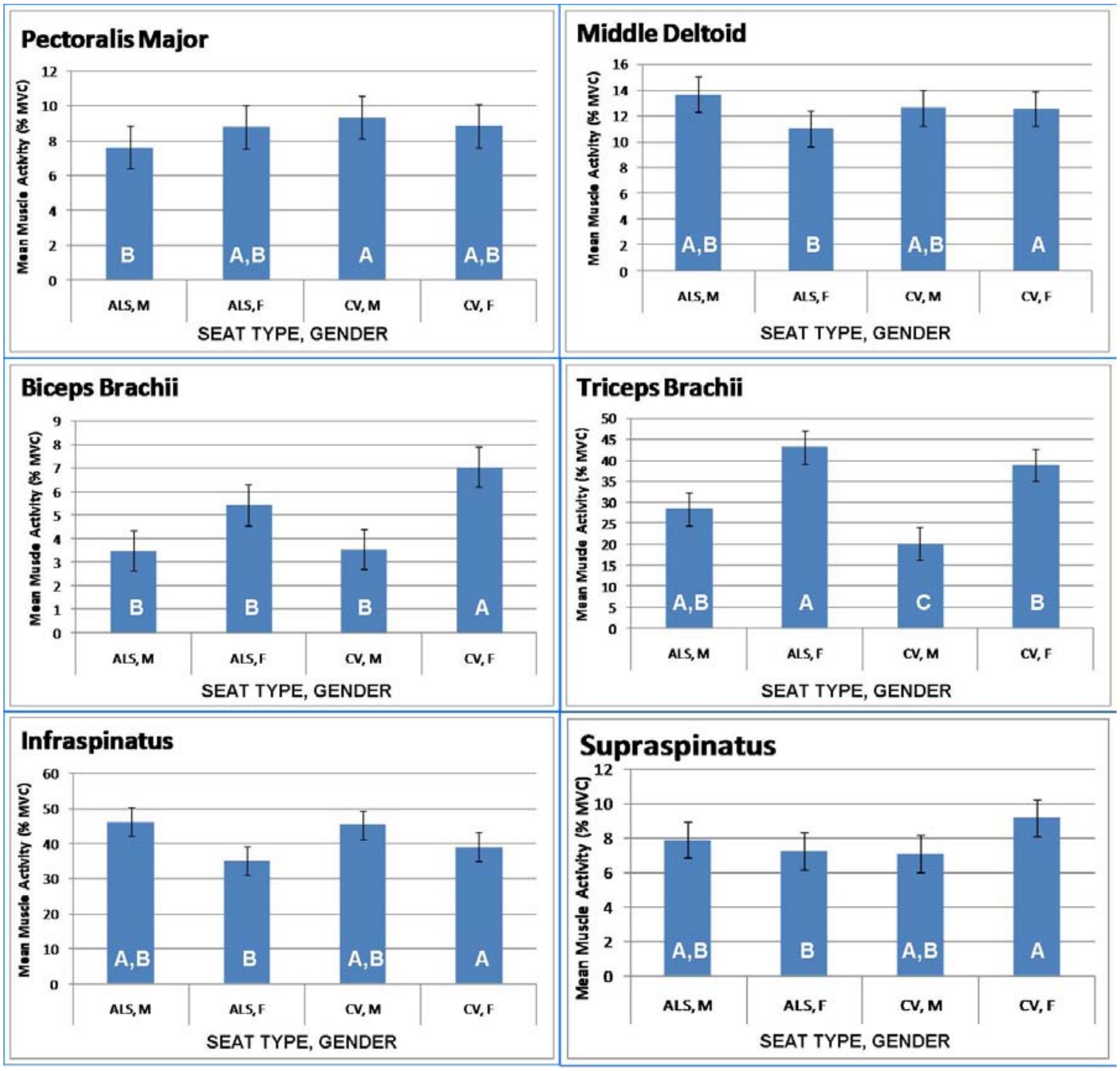


Figure 23: Mean muscle activity interaction between seat type and gender for pectoralis major (PECC), middle deltoid (MDEL), biceps brachii (BICP), triceps brachii (TRCP), infraspinatus (INFR), and supraspinatus (SUPR). CV and ALS refer to Crown Victoria and active lumbar support driver seats, respectively. Levels with different letter codes are significantly different.

6.2.2 Rating of Perceived Discomfort (RPD)

For ratings of perceived discomfort (RPD) in the lower back, significant differences existed across MDT locations ($p < .0001$), between seat types ($p < .0001$), and across the three typing task sets (time) ($p = .0035$). MDT location 5 elicited significantly more discomfort in typing tasks than all other locations, and location 6 significantly reduced discomfort compared to locations 3, 4, and 5 (Figure 24). Perceived discomfort in the CV seat (15.4mm) was significantly greater ($p < .0001$) than in the ALS seat (11.1mm). Perceived discomfort also increased with time, as RPD in the first set of typing tasks (11.9mm) was lower than the second set (13.1mm) and significantly lower than the third set (14.7mm) (Figure 25).

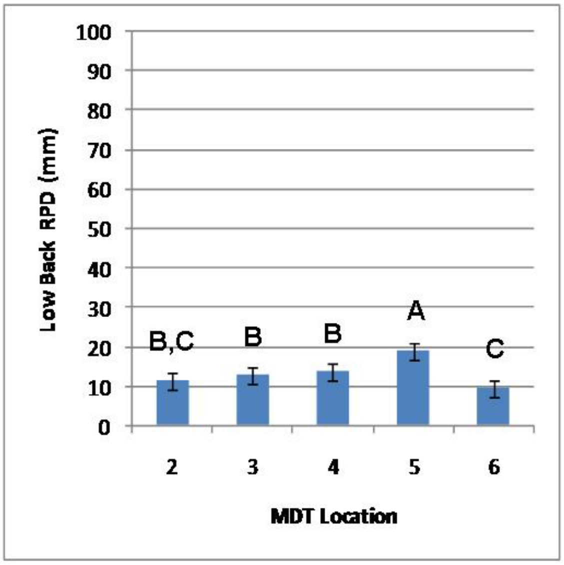


Figure 24: Mean low back rating of perceived discomfort (RPD) across MDT location. RPD reported in mm. Levels not separated by the same letter are significantly different.

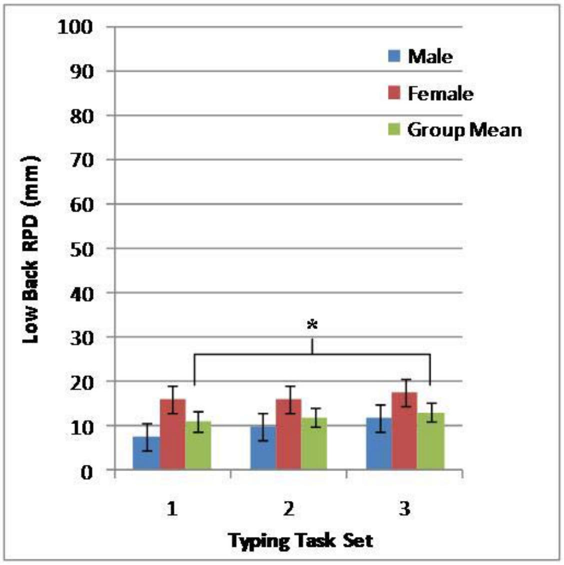


Figure 25: Mean low back perceived discomfort across time, male, female and group mean. A * indicates a significant difference.

In the right shoulder, significant differences in perceived discomfort existed across MDT locations ($p < .0001$). RPD in location 5 > location 3 > location 4 > locations 2 and 6 (Figure 26). A significant MDT location by gender interaction effect ($p < .0001$) was also present for right shoulder RPD, but this effect was not consistent between genders across MDT locations.

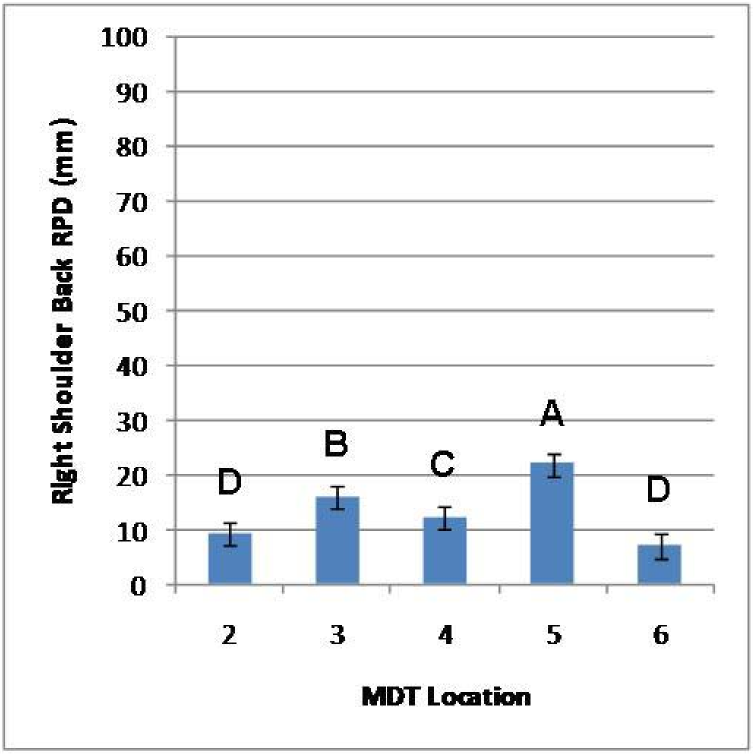


Figure 26: Mean low back rating of perceived discomfort (RPD) across MDT location. Levels not separated by the same letter are significantly different.

6.2.3 Shoulder Elevation Angle

Few differences were seen in the mean elevation angle between the humerus and long axis of the torso. Significant differences in this mean shoulder elevation angle were shown only across MDT locations ($p = .0022$): Locations 3 and 4 elicited a greater elevation angle than location 6 (Table 19). Gender differences in elevation angle were not present as a main effect, but a seat type by gender interaction effect ($p = .0055$) was present. Elevation angle for male participants in the ALS seat (40.9°) was significantly lower than males in the CV seat (44.5°), however, these values were both statistically similar to female measures on both the ALS seat (48.7°) and CV seat (47.8°). Gender seemed have the greatest impact on this interaction effect.

Table 19: Mean Elevation Angle across mobile data terminal (MDT) locations. Levels not separated by the same letter are significantly different.

Location	Significance Level		Mean Elevation Angle (°)
3	A		47.60
4	A		46.46
5	A	B	46.13
2	A	B	44.49
6		B	42.68

6.2.4 Mean Resultant Dynamic Shoulder Moment

Differences in mean resultant dynamic shoulder moment emerged across MDT location ($p < .0001$), gender ($p = .047$), and in a location by gender interaction effect ($p = 0.0008$). Upper arm postures for MDT location 5 produced greater mean resultant dynamic shoulder moment than all other locations, followed by location 2, location 6, and locations 4 and 3 (Figure 27). Approximately 20% higher values existed for male participants (7.06 N·m) than female participants (5.90 N·m).

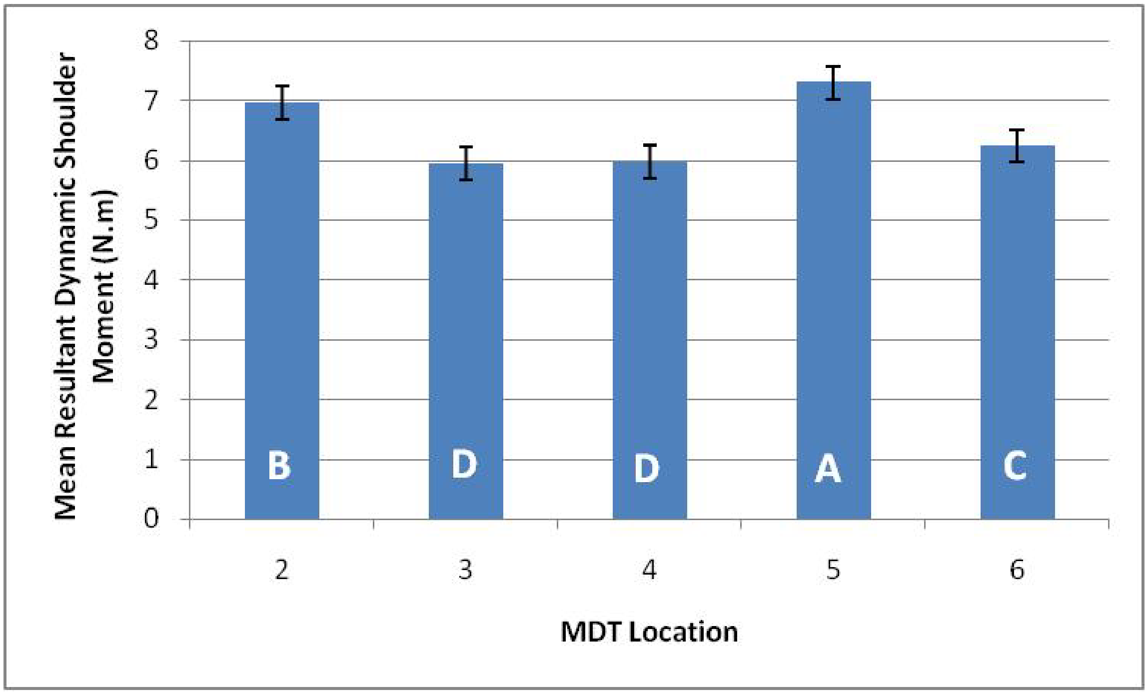


Figure 27: Mean resultant dynamic shoulder moment across MDT location. Levels not separated by the same letter are significantly different.

6.2.5 EMG-Based Total Muscle Force

No significant main effect differences emerged for any of the tested independent variables, however, a significant seat by gender interaction effect (p = .0014) was present. Total muscle force for male participants in the ALS seat (1191.8N) was significantly higher than males in the CV seat (1121.9N), however, these values were both statistically similar to female measures on both the ALS seat (1247.9N) and CV seat (1266.6N). Gender seemed have the greatest impact on this interaction effect.

6.2.6 Model-Based Total Predicted Muscle Force

Total muscle force as predicted by SLAM showed significant differences across seat type (p = .0054). Though an MDT location main effect was present overall, only one level of significance existed. These total muscle force estimates ranged from 367.9 ±

145.5N (location 5) to 406.2 ± 166.8N (location 4) (Figure 28). Total predicted muscle force in the ALS seat (398.2 ± 157.7N) was greater than in the CV seat (371.9 ± 94.7N). Typing task set (time) and participant gender had no significant effect on model-based total muscle force.

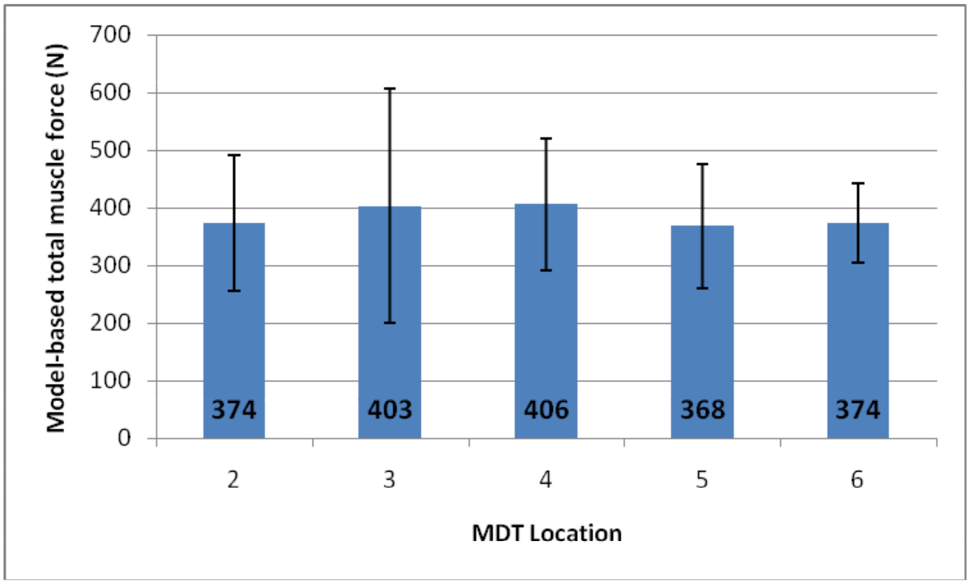


Figure 28: Model-based total predicted muscle force across MDT location. All levels are statistically similar.

6.2.7 Outcome Measure Agreement Matrix

The outcome measure agreement matrix served as a method by which to rank MDT locations within seat type based on a consolidation of all of the experimental outcome measures. Slight differences were seen between the two measured seats (CV and ALS) for both average ranks and the rank orders across MDT locations. Location 6 was ranked best as it produced the lowest average rank for both driver seat types. Overall, locations 2 and 4 ranked second followed by locations 3 and 5 (Tables 20 and 21). Specific rank order for the ALS seat was identical to overall rank order, however, location 4 produced a lower score (1.42) than location 2 (1.50) in the CV driver seat. The rank order of mean elevation angle, resultant dynamic shoulder moment and model-based total predicted muscle force were almost identical between the two seat types, whereas RPD and EMG-based total muscle force had distinctly different rank ordering between the seats.

Table 20: Outcome measure agreement matrix for ALS driver seat.

	Outcome Measure Rank				
Outcome Measure	**Location 2**	**Location 3**	**Location 4**	**Location 5**	**Location 6**
Shoulder RPD	1.5	3	2	4	1
Low Back RPD	1.5	1.5	2	3	1
Mean Elevation Angle	1	1	1	1	1
Mean Resultant Dynamic Shoulder Moment	2	1	1	3	1
EMG-based Total Muscle Force	2	2.5	1.5	3	1
Model-based Total Muscle Force	1	1	1	1	1
Average Rank	1.50	1.67	1.42	2.50	1.00
Rank Order	**3**	**4**	**2**	**5**	**1**

Table 21: Outcome measure agreement matrix for CV driver seat.

	Outcome Measure Rank				
Outcome Measure	**Location 2**	**Location 3**	**Location 4**	**Location 5**	**Location 6**
Shoulder RPD	1.5	3	2.5	4	1
Low Back RPD	1.5	2	2	3	1
Mean Elevation Angle	1	1	1	1	1
Mean Resultant Dynamic Shoulder Moment	2	1	1	2	1
EMG-based Total Muscle Force	1.5	1.5	1	2	1.5
Model-based Total Muscle Force	1	1	1	1	1
Average Rank	1.42	1.58	1.42	2.17	1.08
Rank Order	**2**	**4**	**2**	**5**	**1**

7.0 Discussion

7.1 Addressing the Specific Aims and Hypotheses

Field Quantification of Physical Exposures in Police Cruiser Operators

The specific aims of the field investigation were to identify and characterize the most common daily activities of traffic division officers and to quantify cumulative exposures in the context of whole body activities. Using this digital video collection method of activity characterization, the typical daily task set was quantitatively and explicitly described for a sample of mobile police officers. Ten common daily activities were identified and evaluated in terms of absolute time and percent time of a typical daily shift.

Hypothesis 1

It was hypothesized that shoulder elevation angle would be influenced by mobile data terminal location. Due to upper limb posture changes required to complete the simulated police typing tasks, variation of the mobile data terminal location did lead to significant changes in the mean shoulder elevation angle, however, effects did not exist for all comparisons. As a whole, hypothesis 1 was supported by the results of this investigation.

Hypothesis 2

It was hypothesized that right shoulder moment and participant shoulder discomfort would be minimized in the mobile data terminal location that minimizes shoulder elevation angle. Shoulder elevation angle was minimized for the self-selected mobile data terminal location, although it significantly differed from only two other locations. In terms of non-significant differences, trends in shoulder elevation angle and perceived discomfort agreed for the self-selected and current mobile data terminal locations. Trends in mean resultant dynamic shoulder moment did not follow those of shoulder elevation angle. Hypothesis 2 was not supported by the results in this investigation.

Hypothesis 3

It was hypothesized that ratings of perceived discomfort for the right shoulder would be minimized for the self-selected mobile data terminal location. The self-selected location did reduce participant discomfort compared to three of the four tested mobile data terminal locations, however, it was statistically similar to discomfort ratings for the location currently used in observed police cruisers. Hypothesis 3 was supported by the results in this investigation.

Hypothesis 4

It was hypothesized that average ranks across all outcome measures would show differences across mobile data terminal locations and that the self-selected location would have the lowest average rank. Average ranks were nominally different across MDT locations, however, these differences were not statistically tested. The self-selected mobile data terminal location did elicit the lowest average rank, suggesting that it presents the least physical risk among the tested locations. Hypothesis 4 was supported by the results in this investigation.

7.2 Field Quantification of Physical Exposures in Police Cruiser Operators

Few studies have previously investigated the longitudinal (full shift) physical exposures officers experience in a modern mobile police environment. This investigation characterized specific officer activities and identified the duration for which these activities were performed. Two distinct work environments were identified for these officers: in-vehicle and out-of-vehicle. Out-of-vehicle activities encompassed more than half of the daily shift activities (Table 12), identifying them as having potential for intervention to reduce the prevalence of musculoskeletal symptoms among this population. However, due to the highly variable nature of these activities, and legal and logistical difficulty in documenting them, this study focused on in-vehicle activities. The data generated in this study provides a rigorously ranked quantification of percentage time spent in various in-vehicle activities that was previously unavailable for modern mobile police operations. Due to the absence of high load activities performed in the vehicle, cumulative postural activity exposures were chosen as a method to identify possible aspects of the work activity or workplace that would be most beneficial to address with design modifications. In-car activities are further divisible into driving and non-driving activities. Onset of low back pain or discomfort has previously been identified for occupational driving activities in general (Porter & Gyi, 2002; Porter, Porter & Lee, 1992), as well as for the flexed lumbar postures associated with such activities (Beach *et al.*, 2008; Dunk & Callaghan, 2005). The level of this discomfort is directly related to the amount of occupational driving exposure (Porter, Porter & Lee, 1992). In our current investigation, single-handed (left arm) driving (Figure 29a) made up 50.3 ± 15.7% of the in-vehicle activities performed by the officers on a time basis (Table

13). As driving is a functionally necessary component of this occupation, as well as many others, limited potential modifications to the environment unique to this population seem pragmatic. Further, as much work continues to be done on reduction of spinal loading through automotive seating investigations (Gyi & Porter, 1999; Carcone & Keir, 2007; Durkin *et al.*, 2006) the focus of this study was on possible intervention in this specific population with non-driving, in-vehicle activities and equipment interfaces.

Figure 29: Sample images of driver activities for (A) left-handed driving, (B), on-paper documentation, and (C) two-handed mobile data terminal use.

High exposures to non-driving, or peripheral, police activities present additional risk to mobile officers. Postural adaptations to driving task layout changes are accomplished primarily by changes in limb posture, whereas torso posture remains largely unaffected (Reed *et al.*, 2000). Thus, officers are exposed to repetitive or static upper limb loads which may lead to musculoskeletal impairment (Magnusson & Pope, 1998). In general, extended upper limb exposures or flexed and abducted postures in these peripheral tasks increase cumulative shoulder moments (Nussbaum *et al.*, 2001). Increased muscular loads associated with these moment increases may induce local muscular fatigue and increase the risk of upper limb problems (Nussbaum, 2001).

On-paper documentation (Figure 29b) and mobile data terminal use (Figure 29c) emerged as the best apparent candidates for attempted mobile police environment interventions, based on cumulative exposures. Despite improvements in communication that accompany modern mobile data terminals, officers are still required to complete various daily logs on paper. Completing various forms of paperwork consumes approximately 20% of the time spent working in the vehicle. There is no fixed location or standard method for completing this documentation in the vehicle. As a result, officers use different strategies and individualized joint postures to complete this task.

Mobile data terminal use is another area of concern as it represented over 13% of in-car time activities performed by officers (combined one and two-handed use). The mobile data terminal as currently configured has minimal adjustability, and thus its location and orientation are not easily repositioned to reduce upper limb and low back loading associated with the arm extension and trunk axial twisting its use requires. These specific problems are not common to all police fleets, but not unique to the fleet observed in this study. Supportive devices are available to minimize such problems, but are not designed to function in the mobile environment (Milani, 2008). Large swing arm or "boom" mounts and removable MDT mounting solutions have been implemented in unique applications, but have not motivated fleet-wide adaptations (Brewer, 2008). Given the significant investment required to outfit a police fleet with modern MDT systems compared to the cost of mounting hardware, it may be worth upgrading current mounting solutions (Milani, 2008). The next aspect of this line of study investigated the influence of both MDT location and driver seat characteristics on postural, psychophysical, and physiological experimental measures.

7.3 The Evaluation of Mobile Data Terminal Location During a Simulated Police Patrol Task Set

This study has identified that MDT location and driver seat type differences influence postural, psychophysical and physiological measures of the upper limb and torso during simulated police patrol. The differences that do occur, however, are not homogeneous across all recorded and calculated outcome measures, so they should be discussed both individually, within each effect, and with regards to a global outcome measure ranking system, the average ranks and rank order.

7.3.1 Effect of Mobile Data Terminal Location

Ratings of Perceived Discomfort

An MDT location main effect was present for both low back and right shoulder perceived discomfort, showing that spatial configuration changes may potentially reduce the prevalence of musculoskeletal pain in a mobile police population. There is a marked separation of locations 2 and 6 from the other tested locations. In both body regions, locations 2 and 6 produced significantly less discomfort (Figures 24 and 26). This finding identifies possible configuration changes in a modern mobile police environment. Where this finding comes up short, however, is in the fact that for both body regions, perceived discomfort at locations 2 (LB-11.2mm; Sh-9.4mm) and 6 (LB-9.5mm; Sh-7.1mm) are statistically similar. Location 2 represents the current MDT location used in modern police cruisers, and location 6 represents an MDT location self-selected by each participant. The lack of separation between these two locations suggests that modifications would not change perception. Although this finding may be disappointing as it does not identify an obvious configuration to reduce injury prevalence, it is fundamental information for developing future solutions.

A goal of this study was to identify the location that minimizes discomfort, but it is important to note the location or locations that increased discomfort relative to the current location and perhaps exacerbate the potential for pain and injury prevalence among mobile officers. Location 5 (LB-19.0mm; Sh-22.0mm) produced significantly more discomfort than all other locations in both the low back and the right shoulder. This location was tested because it does fit within the spatial confines of a police cruiser, however, greater trunk axial twisting and static shoulder abduction and flexion are apparent with increased MDT distance from the driver. Further, to remain upright in the driver seat, its use allowed only single-handed operation. A majority of participants (85%) found this single-handed operation difficult and opted for two-handed operation despite increased loading. These static loads in the upper limb coupled with awkward seated postures present high risk for muscular strain, impingement or tendonitis (Magnusson & Pope, 1998; Chaffin, Andersson & Martin, 2006). In attempting to identify the best MDT location based on minimization of perceived discomfort, location 5 is not a candidate for future use.

The association between musculoskeletal discomfort and task factors (MDT location and driver seat type) cannot be used as a sole means for evaluation of task injury risk. This link does not eliminate the possibility of psychosocial factors for the development of pain and injury, specifically among MDT users (Faucett & Rempel, 2007). However, musculoskeletal discomfort has been shown to be a precursor to developed disorders, and a reduction in injury prevalence can be achieved by improvement in workplace ergonomic (postural and physiological) factors (Sauter et al., 1991). Given that with this current data set psychosocial factors were controlled for, recorded measures of perceived discomfort (RPD) are an appropriate means for evaluating the tested police cruiser configurations.

Muscular Force and Exertion Estimates

Unlike perceived discomfort, estimation of both corporate and individual muscle demand and their relative contributions are more direct indicators of physical risk, and are essential to understanding the mechanism of mobility and stability in the shoulder for a given action (Chang *et al.*, 2000). The relative contributions of muscles in an effort to produce movement in this simulated police patrol task set were evaluated by two methods: surface EMG and mathematical force predictions.

Muscular activity via surface EMG is a very important tool in assessing physical injury risk in these typing tasks in general, as well as identifying whether configuration changes affect this risk. The static loads required for these typing tasks present risk for initiation of local muscle fatigue. As part of an amplitude probability distribution function, the acceptable activity level guideline for the 50th percentile or half of a daily shift is 12-14% MVC (Mathiassen & Winkel, 1991). Mobile officers perform typing and documentation tasks in these static upper limb postures for 34% of the time spent in the police cruiser (McKinnon, Callaghan & Dickerson, *submitted*), thus activity levels approaching this guideline are a site of fatigue-based injury risk. In this study, five muscles (UTRP, ADEL, MDEL, TRCP, INFR) presented mean activity levels greater than 10% MVC for typing tasks and present potential risk for musculoskeletal pain or injury (Tables 16-17). Overall, variability in muscle activity across subjects suggests that risk may be present for all recorded muscles (Table 18). Addition of one standard deviation to individual muscle means presents muscle activity greater than 10 %MVC for all muscles but the biceps. For the muscles that present a sample mean above 10 %MVC, the high intersubject variability suggests that many participants may be at an even greater risk for injury.

Overall, the nature of these typing tasks contain an inherent risk for mobile officers when performed on a daily basis, but it is still essential to identify whether or not changes in MDT location influence the magnitude of this risk. In a pattern similar to RPD scores, all significant muscles noted a tendency of muscle activity highest in locations 3 and 5, followed by location 4, and lowest in locations 2 and 6. Again, the goal of this study was to identify specific sites of risk and potential configuration changes as a result of that risk. Since muscle activity level was consistently lowest in tasks performed at locations 2 and 6, futher discussion can be narrowed to these locations. Significant MDT location main effect differences were found for MDEL ($p = .0015$), PDEL ($p < .0001$), BICP ($p = .048$), and SUPR ($p < .0001$), however, post-hoc analysis (Tukey HSD) showed muscular activity level for tasks performed at locations 2 and 6 to be statistically similar for all of these muscles. A physiological link can be made to strengthen past evidence that self-selected postures during typing tasks minimize operator pain and injury risk (Babski-Reeves, Stanfield, & Hughes, 2005; Helander & Zhang, 1997). Again, the lack of separation between these two locations suggests that the current MDT location is ideal for minimizing muscular activity.

A mathematical musculoskeletal shoulder model was also used to evaluate the posture-based demands of these simulated police typing tasks. The Shoulder Loading Analysis Modules (SLAM) model (Dickerson, Chaffin & Hughes, 2007) produced estimates of model-based total predicted shoulder muscle force. A significant MDT location main effect existed for total predicted muscle force, but post-hoc analysis revealed only one level of significance across locations. It appears that the magnitude of predicted corporate muscular loading in the shoulder system did not vary much across MDT locations, but perhaps the changes in the direction of loading increase activity level in individual muscles. High variability across subjects also resulted in an inability to distinguish values across the locations (Figure 26).

Resultant Dynamic Shoulder Moment

Evaluation of resultant dynamic shoulder moment follows a similar analysis to the other outcome measures that have been discussed. Shoulder joint moments are known to increase with increased reach distance and increased shoulder flexion angle (Giroux & Lamontagne, 1992; Anton *et al*., 2001). Consequently, increased moments have the potential for causing fatigue or acute strain, which are recognized factors for the development of cumulative trauma disorders (Anton *et al*., 2001). Minimizing reach and minimizing elevation angles may be one method of reducing these disorders (Wos *et al*. 1992). Thus, the tested MDT location that minimizes resultant dynamic shoulder moment in this study may be identified as the best location for the MDT.

As with measures of perceived discomfort and muscle activity, this moment measure in typing tasks performed at MDT location 5 (7.30 N·m) was greater than all other locations. Moment was not, however, minimized at locations 2 (6.95 N·m) and 6

(6.24 N·m), but rather at locations 3 (5.95 N·m) and 4 (5.96 N·m) (Figure 27). This finding contradicts other outcome measures in this study, as well as previous work. In dynamic reach tasks, shoulder moment is the most consistent physical predictor of perceived effort (Dickerson, Martin & Chaffin, 2007), which is not the case here. Disagreement with surface EMG and RPD outcomes may be attributed to upper arm and forearm interaction. EMG was measured only for upper arm and torso musculature, and perceived discomfort was only measured for low back and right shoulder, but demands of the structures (muscle, tendon, ligament, bone) in the forearm and hand may also vary across typing postures at each MDT location. The SLAM model incorporates a full set of upper limb joint coordinates (including elbow, wrist and hand) and accounts for these demands, whereas EMG and RPD do not. Another explanation for this disagreement between measures is that resultant moments were calculated in this study. Disagreement between resultant moment and muscle force model predictions of perceived effort exist for load transfer tasks (Dickerson, Martin & Chaffin, 2007), with moments typically performing better. Mechanically, resultant external joint moments do not directly map onto individual muscle requirements. Differences in the directional components of the resultant moment may require different muscular responses, even if the magnitude of the resultant moment is unchanged.

Shoulder Elevation Angle

Shoulder elevation angle should be a driving measure for determining the effect of MDT location in this study. Past studies have confirmed that as shoulder elevation angle increases, the load on the shoulder also increases (Giroux and Lamontagne, 1992, Sporrong and Styf, 1999). The typing tasks performed at each of the MDT locations were identical, and thus should only see posturally driven demand changes. This investigation should follow this evidence for determining relative risk of injury across MDT locations. As elevation angle increases, perceived discomfort, individual muscle activity levels, total muscle force (EMG-based and model-based), and resultant dynamic shoulder moment should all increase accordingly.

These relationships with elevation angle were partially maintained for all other outcome measures, with the exception of resultant dynamic shoulder moment. Shoulder elevation angle is smallest for typing tasks performed at MDT location 6 (42.7°), but this is only significantly different from angle at location 3 (47.6°). With lack of distinct statistical differences across all locations, it is difficult to comment on the rank ordering of elevation angles compared to other outcome measures. It is important to note, however, that again this outcome measure was lowest for typing tasks performed at locations 2 (44.5°) and 6. Prior to data collection, it was considered that postural variation may wash out significant effects in this outcome measure. Typing postures were expected to be quite different, especially across the wide range of participant statures in this investigation (Table 6). However, elevation angles were very consistent at all MDT locations with angles ranging from 42.7° to 47.6° and all standard deviations between 2.13° and 2.14°.

Outcome Measure Agreement Matrix

This investigation used six different outcome measures in an attempt to evaluate five different MDT locations within a simulated police cruiser. Ideally, all measures would agree with one another, however, some rank ordering contradictions did occur. Perceived discomfort, EMG-based total muscle force, resultant dynamic moment, predicted muscle force, and elevation angle were each effective in evaluating injury risk for a simulated police typing task across MDT locations, however, an agreement matrix was also appropriate to produce a global ranking that incorporated all these outcome measures. The agreement matrix showed slight differences between seat types (CV and ALS) for average rank values as well as order of the average ranks (Tables 20 and 21).

The goal of this investigation was to improve the current mobile police cruiser configuration by evaluating a set of possible MDT locations. In agreement with our hypothesis, the self-selected MDT location, location 6, had the lowest rank of all locations, indicating that it presents the least risk of injury of the tested locations. Through previously discussed outcome measures, a logical link can be created between self-selection and average rank across all outcome measures. Discomfort tends to be minimized in self-selected postures (Babski-Reeves, Stanfield, & Hughes, 2005), and shoulder angle and thus resultant shoulder moment correlate with discomfort rankings (Dickerson, Martin & Chaffin, 2006). Therefore, it is not surprising that the self-selected typing location presents the best ranking among the tested locations.

Ranked second among the tested locations were location 2, which represents the current MDT location, and location 4. In an effort to recommend change to the current configurations that reduces risk and prevalence of musculoskeletal injuries among the mobile police population, two key conclusions can be drawn from this.

Firstly, the best way to improve this situation based on posture induced changes is to improve the adjustability of the MDT mounting system. To give each officer a truly self-selected MDT location will improve low back and shoulder perceived discomfort and elevation angle among the tested locations, and reduce resultant dynamic shoulder moment from the current location. As currently configured, the MDT allows for small tilt and swivel adjustments, but full adjustability is not available to each officer at the beginning of their shift.

Secondly, for all individual outcome measures, except resultant dynamic shoulder moment, the self-selected MDT location (location 6) is statistically similar to the current MDT location (location 2).Therefore, the current MDT configuration provides negligible room for improvement if it remains fixed within the current spatial constraints provided by other necessary equipment within the cruiser. Also, though large inter-participant variations did exist, mean placement of the self-selected MDT location was very similar to the current location. The largest differences seen were the ALS seat self-selected location being 5.5cm and 3.9cm closer to the driver in the anterior-posterior and medial-lateral directions, respectively (Table 9). Due to the similarity of these locations, statistical similarity in outcome measures is not surprising.

The outcome measure agreement matrix showed locations 4 and 2 to have identical average ranks within the CV seat as well as across both driver seats. This suggests that location 4 may be comparable to location 2, however, individual measures showed contradictory findings. Because average rank is calculated from six outcome measures, major differences in one outcome measure may have inflated the average rank score. Location 2 was consistently better or comparable to location 4 for five of the six recorded outcome measures. The only exception was mean resultant dynamic shoulder moment (Tables 20 and 21). The low score of location 4 and subsequent high score of location 2 within this outcome measure skewed average rank towards location 4. Though average ranks did provide a global ranking system across all measures, all measures were weighted evenly, and thus, the average rank scores were evaluated in conjunction with statistical analysis of each measure individually.

Devices have been developed specifically for police applications that modify the police cruiser from the current spatial constraints, but are not designed for a mobile environment (Milani, 2008). Other systems have been developed integrating voice recognition software that allows the officer to communicate without using key presses and typing tasks necessary with current MDT systems (i.e. Project 54 (Kun, Miller & Heeman, 2005)). Such systems may reduce posture based loading experienced by mobile officers, but this loading and risk of injury have not yet been investigated. Given the lack of distinction between the MDT locations tested in the current investigation, it is likely that technology changes, rather than structural ones, may have the greatest influence on further reducing injury risk.

7.3.2 Effect of Driver Seat Type

The use of the ALS seat reduced participant discomfort in the low back compared to the standard CV seat in this simulated police patrol investigation. Mean low back RPD showed statistically significant decreases from 15.4mm in the CV seat to 11.1mm in the ALS seat. In a similar investigation by Donnelly, Callaghan & Durkin (*in press*), specific seat aspects which differ from a standard seat were identified as potential factors in reducing RPD, and these factors hold true for this investigation. First, the ALS seat contained a shortened seat pan to accommodate shorter officer thigh lengths. Second, the seat included foam structure modifications to accommodate the police duty belt and provide active torso support through interaction with the police protective vest. Third, the seat allowed manual anterior-posterior and superior-inferior lumbar support adjustment, and produced cyclic anterior-posterior-superior-inferior excursions of the lumbar support. It is difficult to isolate the effect of each of these seat aspects, and perhaps more appropriate to attribute reduction in discomfort to the seat as a whole. Increased adjustability likely improved the ability of participants to adjust peak pressures imposed by equipment attached to the police duty belt worn for the testing sessions (Donnelly, Callaghan & Durkin, *in press*). A reduction in such lumbar peak pressures has been shown to reduce reporting of perceived discomfort (Mergl *et al*., 2005).

The interaction of seat aspects likely increased overall support and maintained lumbar lordosis of the lumbar spine throughout the testing sessions. Increased support has been shown in the past to better maintain lumbar lordosis close to that of a standing posture (Mahksous *et* al., 2003). The ability to maintain this lumbar lordosis while seated and also reducing peak pressures caused by police equipment is essential for reduction in low back perceived discomfort (Mahksous *et al*., 2003; Donnelly, Callaghan & Durkin, *in press*). The increased adjustability of the ALS seat likely achieved these goals using a combination of each modified seat aspect.

As may be expected, seat type had little effect on upper limb measures. Perceived discomfort in the right shoulder, resultant dynamic shoulder moment, and shoulder elevation angle were all statistically similar between seat types. Seat type did have a statistically significant effect on the muscle activity of six of the nine recorded muscles (PECC, ADEL, BICP, TRCP, INFR, and SUPR); however, the clinical significance of this finding is unlikely. In general, activity level was reduced for the ALS seat compared to the CV seat for all recorded muscles, except for UTRP and TRCP (Figure 22). Among these muscles, seat type differences in activity level ranged only from 0.6 %MVC for SUPR to 1.7 %MVC for ADEL. During tasks in an automotive driver seat, postural adaptations are accomplished primarily by changes in limb posture, rather than torso adjustments (Reed *et al*., 2000). This may justify the fact that these measures show limited differences between seat types. This also suggests that MDT location or interaction modifications are the best solution to reduce upper limb loading and subsequent injury. In addition, injury risk reduction in the low back may be more effectively realized with seating modifications rather than MDT modifications.

7.3.3 Effect of Time and Gender

As noted, occupational driving itself is a musculoskeletal risk factor and may lead to driver discomfort, pain and injury. Increased time or driving exposure generates a greater level and prevalence of driver discomfort (Porter & Gyi, 2002; Porter, Porter & Lee, 1992). In this investigation low back perceived discomfort corroborated this evidence and increased with time through the testing sessions. Mean low back RPD increased from 11.9mm to 13.1mm to 14.7mm during the first, second, and third sets of typing tasks, respectively.

Again, the goal of this investigation is to provide evidence-based recommendations to reduce injury risk among mobile police officers, primarily through police cruiser configuration changes. Police patrol shifts are generally between 8 and 12 hours, and with in-car activities accounting for 49.6% of that daily shift (Table 14), time while seated is a key issue that should be discussed when suggesting any changes.

It is important to note that the field aspect of this study looked at time-based physical exposures to mobile officers over the course of a daily shift, and the laboratory aspect subsequently compared these exposures across different cruiser configurations. The belief in this investigation was that with task characteristics held constant—as they were at all tested MDT locations—short duration task demands may reflect differences in long duration demands. Because the laboratory investigation was only 1-hour long, it is difficult to draw conclusions regarding the cumulative loading in the evaluated typing tasks. However, it is likely that effects demonstrated in this investigation could be magnified when considering cumulative loading parameters. The primary area of concern is mean muscle activity. Though the current (location 2) and self-selected (location 6) MDT locations tended to elicited the lowest mean muscle activity level across all recorded muscles, a measure of cumulative muscle activity may provide a more appropriate interpretation of long-term mobile police exposures in the upper limb and low back.

Because of the time effect in this investigation, the overall benefit of the ALS seat is also difficult to discern. Current investigations are being done with this ALS seat at the University of Waterloo to evaluate its effectiveness in reducing long term discomfort as well as improving posture-based factors in the short term.

Gender of the participants in this investigation had little effect on most of the outcome measures. Apart from individual muscle activity levels during the typing tasks, only resultant dynamic shoulder moment showed a significant difference with mean moments of 7.06 N·m for male and 5.90 N·m for female participants. Any gender-based torso responses are, however, unavailable at this time. Gender differences exist for lumbar spine, pelvis and trunk angles, which can be applied to this automotive seating application (Dunk & Callaghan, 2005). Further analysis with lumbar angle and seat interface pressure are required to make any gender-based conclusions about low back injury risk.

Gender played a significant role in muscle activity level for both biceps and triceps. Mean activity level was higher for female participants in both muscles: 6.3 (± 3.8) %MVC (female) vs. 3.5 (± 2.6) %MVC (male) for BICP; 41.0 (± 16.5) %MVC (female), vs. 24.3 (± 10.9) %MVC (male) for TRCP. Within female participants, both biceps and triceps muscle activity were highly variable, however, inter-participant trends in activity level of these two muscles were similar. Three female participants had recorded activity levels well above other participant scores for biceps (11.0, 8.2, and 5.9% MVC) and triceps (41.7, 60.2, and 50.7% MVC). With these three participants removed, female mean muscle activity level was 3.4% MVC for biceps and 24.9% MVC for triceps, both similar to male values. Previous studies have shown no gender differences in muscle activity level for similar tasks (Blangsted, Hansen & Jensen, 2003; Nordander *et al.*, 2003), and the results of this study are comparable with these participants removed.

Increased co-activation is a possible explanation for the increased muscle activity in these identified subjects. Upper limb elevation angle differences were not seen and task requirements were identical between genders, thus muscle activity differences are likely due to differences in task performance strategies. Female users tended to operate computer-based tasks with more extreme postures, such as increased shoulder abduction, wrist extension, and ulnar deviation (Karlqvist *et al*., 1999), as well as use a higher number of keystrokes (Blangsted, Hansen & Jensen, 2003). An increased typing rate requires increased accuracy for the task, which has been linked to an increased level of co-contraction in the upper limb musculature (Gribble *et al*., 2003). Typing task performance was neither recorded nor evaluated in this study, so it is difficult to make any conclusions about performance-based gender differences and accompanying differences in muscle activity levels.

7.4 Limitations

This investigation characterized mobile police officer activities, but also identified mobile police work as highly variable. Standard deviations were as high as 16.7% when characterizing officer activities as a percentage of their total shift. Though the laboratory investigation in this thesis sought to design a simulated police patrol protocol that accurately reflected actual police work, it logistically could not capture this task variability. As a result, a few limitations in the laboratory protocol arise.

This investigation looked primarily at short-term (2-hour) postural, physiological, and psychosocial effects and did not evaluate the potential for any prolonged or fatigue-based outcomes that may correspond more closely with actual police work. Perceived discomfort increased with time, and muscle activity changes may be amplified with a more prolonged task set.

No data was collected for the left side of the body in this study. Participants acknowledged that they often felt more discomfort in the left upper limb than the right due to greater reaching required for two-handed typing. The possibility of missing important physical demands therefore exists.

Preference of one-handed versus two-handed typing presents another limitation of the tested task set. Mobile officers preferred one-handed typing in all cases, and 10.3% and 2.78% of in-car daily activity was occupied by one-handed and two-handed typing, respectively. Among the academic population used for this investigation, however, two-handed typing was preferred in almost all experimental trials.

7.5 Suggestions for Future Investigations

Future investigations could directly address the limitations of this study as well as investigate design and technology changes. Long term simulated police patrol activities are currently being investigated at the University of Waterloo in a study on prolonged lumbar loading. This and future investigations should provide some conclusive evidence regarding the effectiveness of driver seat design changes for use by a mobile police population. These officers differ from occupational drivers in both the equipment that they wear and the task set that they perform. Now that this task set has been characterized, future research can effectively target specific job demands and aspects unique to this population.

The effect of one-handed versus two-handed typing for this simulated police patrol should be scrutinized in future investigations. Postural demands are profoundly different for these different typing styles and may have noteworthy implications on the physical loading in both the right and left upper limb and lower back. Concurrently, further work outlining mobile officer activity needs to be done with a larger sample of officers. Though the first aspect of this thesis did effectively characterize officer activity, the sample size was small and localized to a single police unit. To achieve effective municipal, provincial, or federal design changes, data must be collected for a larger, more representative sample. Such data would further justify the investigation of one-handed, two-handed, or mixed typing styles that directly relate to actual mobile police officer preference.

This investigation aimed to outline possible changes to the current police cruiser configuration, but design and technology changes may be a better long-term solution to reduce risk of injury among the mobile police population. Various design changes ranging from minor to drastic have been and continue to be investigated. These technology and design changes include voice operated systems, which eliminate most physical interface with the system, single-celled police cruisers which allow posterior seat movement for MDT use directly in front of the driver, and wireless handheld devices which eliminate the need for a fixed system. Such changes must be evaluated from both ergonomic, performance and safety stances before they can be endorsed as viable methods to reduce physical loading and subsequent injury risk.

8.0 Conclusions

In documenting and recommending solutions to reduce the physical risk in a mobile police population, this investigation yielded five principle conclusions developed from the specific aims and previously stated hypotheses:

1. Two distinct work environments exist for mobile police officers: in-vehicle and out-of-vehicle. In the vehicle, on-paper documentation and mobile data terminal use are the best apparent candidates for attempted mobile police environment interventions.
2. Variation of the mobile data terminal location leads to significant changes in the mean shoulder elevation angle.
3. Shoulder elevation angle is a moderate indicator of trends in right shoulder perceived discomfort, but a poor indicator of resultant dynamic shoulder moment.
4. Self-selection of mobile data terminal location for the tested typing tasks reduces right shoulder perceived discomfort relative to all tested locations except the currently used location. Thus, self-selection of location does not reduce discomfort compared to modern configurations.
5. A self-selected mobile data terminal location elicited the lowest average rank across all outcome measures, suggesting that it presents the lowest physical risk among the tested locations.

The first aspect of this thesis, Field Quantification of Physical Exposures in Police Cruiser Operators, effectively characterized mobile police activity and identified possible opportunities for ergonomic interventions. This robust activity characterization is an important first effort in moving towards creating improved automotive interior designs that address the set of unique challenges facing mobile police. The ultimate goal is to develop and implement targeted, evidence-based workspace design changes that both effectively maintain officer proficiency and safety while removing or mitigating physical risks.

Through a variety of measures, the second aspect of this thesis, The Evaluation of Mobile Data Terminal Location During a Simulated Police Patrol Task Set, effectively identified police cruiser configurations that reduced loading metrics in a mobile police environment.

A set of five mobile data terminal locations were tested in this investigation including the current location, three fixed locations within the plausible space of a modern police cruiser, and a self-selected location. The self-selected mobile data terminal location, location 6, minimized mean right shoulder elevation angle as well as perceived discomfort in both the low back and right shoulder for a set of simulated police typing tasks. Muscle activity, in terms of percent of MVC, was lowest at the self-selected and current locations for all recorded muscles, with significant effects shown in *m.* posterior deltoid and *m.* supraspinatus. In addition, when seated in the ALS seat, EMG-based total muscle force was minimized at the self-selected location. Average rank, a measure that incorporated all recorded and calculated outcome measures, identified the self-selected location as the best of all tested locations, followed by the current mobile data terminal location.

The current Ford Crown Victoria police cruiser driver seat was also tested against a prototype seat that included an active lumbar support (ALS) system, among other modifications. The ALS seat did effectively reduce discomfort in the low back during a simulated police patrol session. Future work investigating tri-axial lumbar angles and seat pan interface pressure should provide some further insight into the effectiveness of the ALS seat in a mobile police population.

Ergonomics Applications

Overall, a self-selected mobile data terminal location and resultant typing posture reduce physical loading and self-reported discomfort compared to the current location. However, these reductions are not significant for some of the outcome measures and clinically these reductions may not be sufficient to motivate substantial field configuration changes. In order for suggested design changes to occur, definitive reductions in pain and injury risk must occur to offset implementation costs. The self-selection of mobile data terminal location suggested in this study may not achieve these goals. To significantly reduce the risk of injury among the mobile police population and justify changes, future research investigating the physical loading with alternative configuration designs and technology must be conducted, likely with a combination of physical and virtual evaluations.

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Appendix A: Information and Consent Form (*Field Quantification of Physical Exposures in Police Cruiser Operators*)

University of Waterloo

Title of Project: Field Quantification of Physical Exposures in Police Cruiser Operators

Principal Investigator: **Clark Dickerson**
University of Waterloo, Department of Kinesiology
(519) 888-4567 Ext. *37844*

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Purpose of this Study:

More attention is needed in the design of mobile workstations, particularly those in which a large array of bulky equipment is needed, such as the police cruiser. There is a societal mandate to ensure that the safety of police officers entrusted with the public good is made a priority and receives targeted, expert opinion. This study aims to take the preliminary actions (observation) necessary in order to achieve the final goal of improving the working conditions for this important segment of the population.

Procedures Involved in this Study

This study will involve the development of methods to analyze workplace exposures for police officers while in their vehicles. We will unobtrusively observe their usual daily activities and develop methods of data collection following this initial observation. As the environment will undoubtedly present several complications in terms of the exact nature of the data collection, it is difficult to be more specific at present. Data collection will include videotaping and unobtrusive observation, No person will be accompanying the officers in the vehicles.

Personal Benefits of Participation

By participating in this study, you will aid development of methods to analyze workplace exposures for police officers while in their vehicles. By doing so, you will be enabling us to be able to help potentially improve the work environment you perform in on a daily basis. There are no other expected benefits to you.

Risks to Participation and Associated Safeguards

There are no additional risks in participation beyond what is normally experienced on a regular shift. Involvement in this study will in no way affect your job or relationship with the Waterloo Regional Police.

Time Commitment

This study will require no additional time commitment as all observation will be done during a regular shift duration.

Changing Your Mind about Participation

You may withdraw from this study at any time without penalty. To do so, indicate this to the researcher or one of the research assistants by saying, "I no longer wish to participate in this study".

Confidentiality

To ensure the confidentiality of individuals' data, each participant will be identified by a participant identification code known only to the investigators and the research assistants. Videotapes and/or photographs will be stored indefinitely in a secure area, BHM 3034, in a locked cabinet in a locked office. Separate consent will be requested in order to use the videotapes and/or photographs for teaching, for scientific presentations, or in publications of this work.

All paper documentation will be kept in a secured locked office (BMH 3034) indefinitely. All electronic files will be stored indefinitely on a password-protected computer, with file names that protect confidentiality.

Participant Feedback

After the study is completed, the Waterloo Regional Police will be provided with a feedback sheet. A copy of this feedback sheet can be requested from the contact information below.

Concerns about Your Participation

I would like to assure you that this study has been reviewed and received ethics clearance through the Office of Research Ethics. However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, you may contact Dr. Susan Sykes, Director ORE, at (519) 888-4567 ext. 36005.

Questions About the Study

If you have additional questions later or want any other information regarding this study, please contact Dr. Clark Dickerson at 519-888-4567 ext. 37844.

CONSENT TO PARTICIPATE

I agree to take part in a research study being conducted by Dr. Dickerson of the Department of Kinesiology, University of Waterloo.

I have made this decision based on the information I have read in the Information letter. All the procedures, any risks and benefits have been explained to me. I have had the opportunity to ask any questions and to receive any additional details I wanted about the study. If I have questions later about the study, I can ask one of the researchers (list names, departments, telephone numbers of investigators).

I understand that I may withdraw from the study at any time without penalty by telling the researcher.

This project has been reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. I may contact this office (888-4567, ext. 6005) if I have any concerns or questions resulting from my involvement in this study.

______________________________	______________________________
Printed Name of Participant	Signature of Participant
______________________________	______________________________
Dated at Waterloo, Ontario	Witnessed

Consent To Use Video and/or Photographs

Sometimes a certain photograph and/or part of a video-tape clearly shows a particular feature or detail that would be helpful in teaching or when presenting the study results in a scientific presentation or publication. If you grant permission for photographs or videotapes in which you appear to be used in this manner, please complete the following section.

I agree to allow video and/or photographs to be used in teaching or scientific presentations, or published in scientific journals or professional publications of this work without identifying me by name. I understand that I retain the right to withdraw my consent to be videotaped or photographed at any time, and that existing video or photos may be destroyed at my request.

____________________________ ________________________________

Printed Name of Participant Signature of Participant

___________________________ ________________________________

Dated at Waterloo, Ontario Witnessed

Appendix B: Postural and Load Exposure Assessment

Quantifying Physical Exposures in Police Cruiser Operations

~ Postural and Load Exposure Assessment ~

This study is being conducted by researchers at the University of Waterloo in co-operation with the Waterloo Regional Police Services

Please read and complete all pages

University of Waterloo

Police Postural and Load Exposure Assessment

Please complete the following questions prior to mobile shift:

Date (DD/MM/YYYY):______/______/______

Height:______ (ft./cm), **Weight**:______ (lbs./kg), **Age**:______(years), **Gender** (M / F)

Have you suffered a low back injury in the last six (6) months? (Y / N)

Have you suffered an upper limb (arm/shoulder) injury in the last six (6) months? (Y / N)

Shift time (start time to end time):____________(am/pm) to ______________(am/pm)

Area/Region of service:____

Right-handed______ Left-handed______

Overview of objectives and purpose and questionnaire and digital video collection:

The goal of this questionnaire is to investigate driver seat discomfort and cruiser interior inflexibility. This questionnaire is meant to identify limitations and constraints with equipment interfaces, seat adjustability and driver comfort maximization.

Digital video collection is meant to document and quantify low back, shoulder and upper limb postural, joint, and tissue exposures experienced by mobile police officers in a typical workday.

There are two sections to this questionnaire: 1) Seating Environment Discomfort Scale
2) Body Discomfort Scale

At the end of your shift, please add any additional comments with respect to comfort/discomfort you felt were not reflected in the car seat questionnaire.

Thank you.

Automotive Seating Environment Discomfort Scale

To answer each question place a vertical dash [|] **through** *the corresponding line*

No Objections — Extreme Objections

1. In terms of where the **laptop** is located, I have…
2. In terms of where the **radio** is located, I have…
3. In terms of **seat adjustability**, I have…

No Discomfort — Extreme Discomfort

4. Discomfort due to the width of the seat cushion
5. Discomfort due to seat cushion length
6. Discomfort due to seat cushion firmness

No Discomfort — Extreme Discomfort

7. Discomfort produced by the height of the back rest
8. Discomfort due to back rest width
9. Discomfort due to firmness of back rest

No Discomfort — Extreme Discomfort

10. Discomfort created by lumbar (low back) stiffness
11. Discomfort created by shoulder stiffness
12. Discomfort created by upper arm stiffness

Scale Continued on NEXT PAGE

Automotive Seating Environment Discomfort Scale (Continued)

To answer each question place a vertical dash [|] **through** *the corresponding line*

No Discomfort Extreme Discomfort

13. Discomfort produced by low back support |————————————————|
14. The vertical location of the low back support causes… |————————————————|
15. Pressure created from the low back support has… |————————————————|

No Discomfort Extreme Discomfort

16. Discomfort due to computer use |————————————————|
17. Discomfort due to radio use |————————————————|
18. Discomfort caused by getting into car seat |————————————————|
19. Discomfort caused by getting out of car seat |————————————————|

No Discomfort Extreme Discomfort

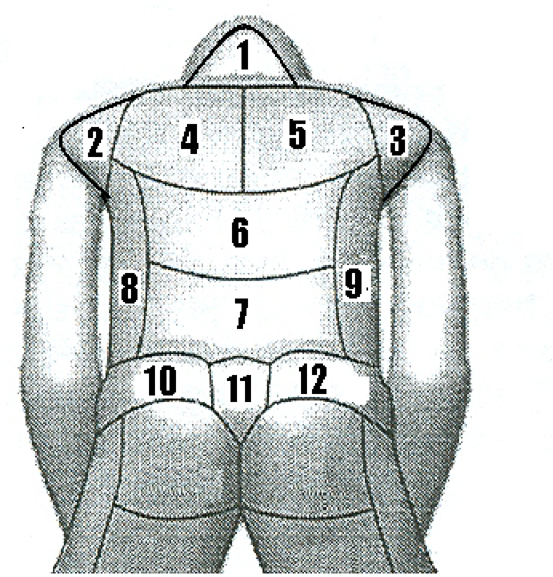
20. Discomfort caused by soft body armour |————————————————|
21. Discomfort caused by side arm/radio |————————————————|
22. Discomfort caused by duty belt |————————————————|
23. Discomfort caused by equipment on back of duty belt |————————————————|
24. Discomfort caused by asp |————————————————|
25. Discomfort caused by seatbelt |————————————————|
26. Discomfort caused by steering wheel |————————————————|

No Discomfort Extreme Discomfort

27. Seating environment overall discomfort level |————————————————|

Body Discomfort Scale

To answer each question place a vertical dash [|] **through** *the corresponding line*



The number displayed in the regions in the diagram above correspond with the numbers in the survey to the right of the diagram.

No Discomfort **Extreme Discomfort**

1. Neck |——————————|

2. (L) Shoulder |——————————|

3. (R) Shoulder |——————————|

4. (L) Upper Back |——————————|

5. (R) Upper Back |——————————|

6. Middle Back |——————————|

7. Lower Back |——————————|

8. (L) Side of Body |——————————|

9. (R) Side of Body |——————————|

10. (L) Upper Pelvis |——————————|

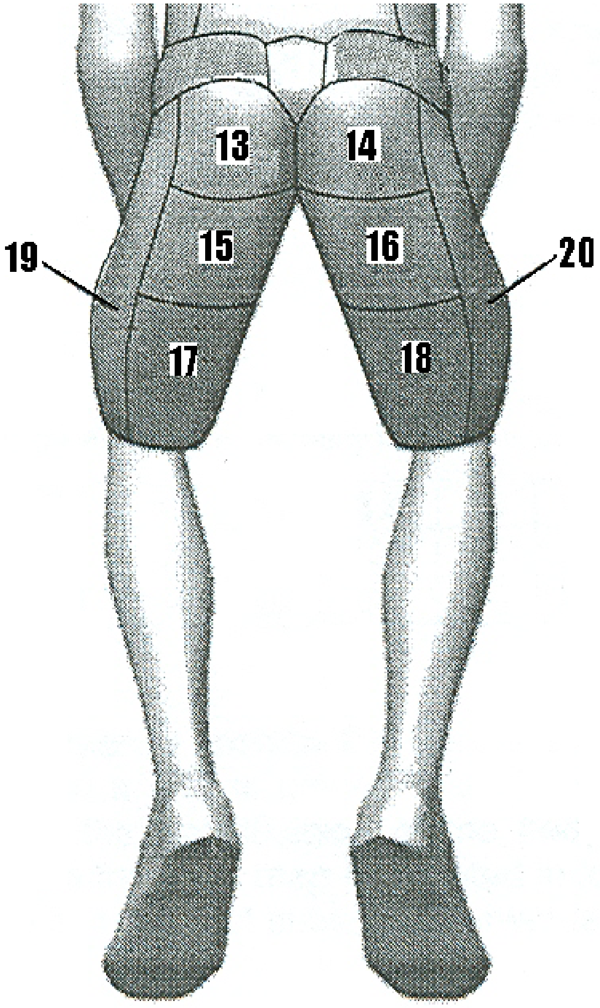
11. Sacrum/tail bone |——————————|

12. (R) Upper Pelvis |——————————|

Scale Continued on NEXT PAGE

Body Discomfort Scale (Continued)

To answer each question place a vertical dash [|] **through** *the corresponding line*



No Discomfort **Extreme Discomfort**

13. (L) Buttocks |————————————|

14. (R) Buttocks |————————————|

15. (L) Upper Thigh |————————————|

16. (R) Upper Thigh |————————————|

17. (L) Lower Thigh |————————————|

18. (R) Lower Thigh |————————————|

19. (L) Side of Leg |————————————|

20. (R) Side of Leg |————————————|

Addition Comment Section

Do you have any suggestions for improvement of interior cruiser equipment locations (e.g. laptop, radio)?

Are there any concerns or comments that you have with respect to the seating environment that were not addressed in the discomfort scales above?

~ Thank you for participating in this Research Study ~

We appreciate your time.

Please return the completed questionnaire to the appropriate person following your shift.

Appendix C: Information and Consent Form (*The Evaluation of Mobile Data Terminal Location During a Simulated Police Patrol Task Set*)

University of Waterloo

Title of Project: The Evaluation of Mobile Data Terminal Location During a Simulated Police Patrol Task Set

Student Investigator: **Colin D. McKinnon**
University of Waterloo, Department of Kinesiology
(519) 888-4567 Ext. 33865

Faculty Supervisor: Clark R. Dickerson
University of Waterloo, Department of Kinesiology
(519) 888-4567 Ext. 37844

Faculty Supervisor: Jack P. Callaghan
University of Waterloo, Department of Kinesiology
(519) 888-4567 Ext. 37080

Purpose of this Study:

Law enforcement personnel experience higher physical demands than those in occupations of a more sedentary nature. In all aspects of police work ranging from physical criminal restraint to automotive pursuit to legal documentation, officers are exposed to physical stressors which may put them at risk for musculoskeletal pain or injury. Mobile police officers, generally traffic division, experience not only acute stressors in emergency response situations, but also cumulative physical exposures with prolonged driving conditions. Such mobile police officers have been shown to experience muscle pain and discomfort as a result of this prolonged occupational driving.

The purpose of this project is to recommend a modified laptop configuration that minimizes physical risk in a simulated mobile police driving and typing. Physical and psychophysical outcome measures will be compared between driver seat types and mobile data terminal locations to determine the police cruiser configuration that minimizes physical risk.

Procedures Involved in this Study

Four mobile data terminal locations and two driver seat designs will be tested with simulated police patrol and typing tasks in two separate 1-hour simulated police patrol testing sessions in a driving simulator setup.

You will be instrumented with surface EMG, a motion tracking system, and seat pressure mapping to evaluate EMG-based muscle stress estimates and model-based muscle stress estimates, and to determine the in-car laptop location and seat design that minimizes resultant right shoulder moment, rate of perceived discomfort and a combination of outcome measures.

You will be instrumented with 9 sets of bipolar surface EMG electrodes. Skin will be prepared by shaving the electrode site with a new disposable razor and site will be wiped with isopropyl alcohol. Surface electrodes will be placed over 9 muscles of the shoulder, chest, and neck (*m.* pectoralis major (clavicular insertion), *m.* upper trapezius, *m.* anterior deltoid, *m.* middle deltoid, *m.* posterior deltoid, *m.* biceps brachii, *m.* triceps brachii, *m.* infraspinatus and *m.* supraspinatus).

Twenty-one reflective markers will be attached to the right arm and torso to track your upper body motion throughout the session. The small markers will be attached directly to the skin with non-irritating double-sided tape.

A set of two 6-second maximum voluntary contractions will be performed for each of the 9 EMG-recorded muscles. This allows for relative evaluation of the EMG recordings.

The testing session itself will consist of 15-minutes of simulated highway driving to pre-condition and achieve a comfortable driving posture. You will then perform a series of four 30-second typing tasks at four different laptop locations. These locations will slight forward-back and left-right modifications from the current position. All positions are to the right of the steering wheel and in front of the right arm rest. Tasks will be separated by 1-minute rest intervals. Locations are plausible modified locations within a police cruiser and will be randomly ordered for each set of typing tasks. Typing tasks consist of key presses in response to on screen instructions and a type-written description of a facial image. You will then complete 15-minutes of simulated driving, another identical series of typing tasks, 15-minutes of simulated driving, and another identical series of typing tasks. You will report their perceived low back and right shoulder discomfort on a 100mm scale for each simulated driving and typing task.

Personal Benefits of Participation

By participating in this study, you will aid development of methods to analyze workplace exposures for police officers while in their vehicles. By doing so, you will be enabling us to be able to help potentially improve the work environment you perform in on a daily basis. There are no other expected benefits to you.

Risks to Participation and Associated Safeguards

You will be performing low-level exertions in both typing and simulated driving tasks. There is minor risk of upper limb and low back fatigue in typing tasks and minor risk of neck, low back and upper limb discomfort/stiffness due to prolonged sitting and screen viewing. These risks are equivalent to those of 1-hour of city driving. Isopropyl alcohol is used for EMG skin preparation, thus, you must not participate in this study if you have a known sensitivity or allergy to rubbing alcohol.

Time Commitment

This study will require 2 sessions each lasting approximately 1.5-hours in duration. If needed, breaks are allowed through the sessions by requesting them from the researcher.

Changing Your Mind about Participation

You may withdraw from this study at any time without penalty. To do so, indicate this to the researcher or one of the research assistants by saying, "I no longer wish to participate in this study".

Confidentiality and Security of Data

To ensure the confidentiality of individuals’ data, each participant will be identified by a participant identification code known only to the investigators and the research assistants. All data will be stored indefinitely in a secure area, BHM 3034, on a password encrypted computer or in a locked cabinet in a locked office. Separate consent will be requested in order to use the videotapes and/or photographs for teaching, for scientific presentations, or in publications of this work.

Inclusion Criteria

Participants must be right-hand dominant males and females between the ages of 18 and 35 years. Males and females will be stature matched; meaning that the stature ranges of participants used will be similar for males and females.

Exclusion Criteria

Participants with a known sensitivity or allergy to rubbing alcohol must not participate in this study. If you have had an injury or experienced any discomfort to the low back or right shoulder area within the last 12 months, you must not participate in this study.

Participant Feedback

After the study is completed, you will be provided with a feedback sheet. A copy of this feedback sheet can be requested from the contact information on the front page of this letter. Results will be available to you by request at the completion of this study approximately in July 2009.

Concerns about Your Participation

I would like to assure you that this study has been reviewed and received ethics clearance through the Office of Research Ethics. However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, you may contact Dr. Susan Sykes, Director ORE, at (519) 888-4567 ext. 36005, ssykes@uwaterloo.ca.

Questions About the Study

If you have additional questions later or want any other information regarding this study, please contact Colin McKinnon (cdmckinn@uwaterloo.ca) at 519-888-4567 ext. 33865 or Dr. Clark Dickerson (cdickers@uwaterloo.ca) at 519-888-4567 ext. 37844.

CONSENT TO PARTICIPATE

Student Investigator:	**Colin D. McKinnon** University of Waterloo, Department of Kinesiology (519) 888-4567 Ext. 33865
Faculty Supervisor:	Clark R. Dickerson University of Waterloo, Department of Kinesiology (519) 888-4567 Ext. 37844
Faculty Supervisor:	Jack P. Callaghan University of Waterloo, Department of Kinesiology (519) 888-4567 Ext. 37080

Recent history of low back or shoulder injury and/or discomfort may confound the results of this study and impose potential physical risk to the participants. I confirm that I have not had an injury or experienced any discomfort to the low back or right shoulder area within the last 12 months.

I agree to take part in a research study being conducted by Dr. Dickerson of the Department of Kinesiology, University of Waterloo.

I have made this decision based on the information I have read in the Information letter. All the procedures, any risks and benefits have been explained to me. I have had the opportunity to ask any questions and to receive any additional details I wanted about the study. If I have questions later about the study, I can ask one of the researchers.

I understand that I may withdraw from the study at any time without penalty by telling the researcher.

This project has been reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. I may contact Dr. Susan Sykes, Director, ORE, at 519-888-4567 ext. 36005 ssykes@uwaterloo.ca if I have any concerns or questions resulting from my involvement in this study.

______________________________	______________________________
Printed Name of Participant	Signature of Participant
______________________________	______________________________
Dated at Waterloo, Ontario	Witnessed

CONSENT TO BE VIDEOTAPED

Videotaping for sessions is a useful tool for detecting any abnormalities in data collection. When using multiple methods of data collection (EMG, motion tracking, seat pressure), it is important to be able to coordinate collected data with physical actions. Recording video of each session will allow us to verify that data and action are matched on a time basis.

I agree to allow videotape and photographs to be recorded throughout the collection period of each of two sessions. I understand that I retain the right to withdraw my consent to be videotaped or photographed at any time, and that existing video or photos may be destroyed at my request.

____________________________	_________________________________
Printed Name of Participant	Signature of Participant
___________________________	_________________________________
Dated at Waterloo, Ontario	Witnessed

CONSENT TO USE VIDEO AND/OR PHOTOGRAPHS

Sometimes a certain photograph and/or part of a video-tape clearly shows a particular feature or detail that would be helpful in teaching or when presenting the study results in a scientific presentation or publication. If you grant permission for photographs or videotapes in which you appear to be used in this manner, please complete the following section.

I agree to allow video and/or photographs to be used in teaching or scientific presentations, or published in scientific journals or professional publications of this work without identifying me by name. I understand that I retain the right to withdraw my consent to be videotaped or photographed at any time, and that existing video or photos may be destroyed at my request.

____________________________	________________________________
Printed Name of Participant	Signature of Participant
___________________________	________________________________
Dated at Waterloo, Ontario	Witnessed

Appendix D: Rating of Perceived Discomfort (RPD) Assessment Sample

Rating of Perceived Discomfort (RPD) Assessment

Date (DD/MM/YYYY):______/______/______

Participant Code:__________________________

This Visual Analog Scale (VAS) discomfort is to be completed for both the lower back and right upper limb after each driving and each typing task.

A total of nine sets of RPD scales should be completed:

- Drive 1
- Type 1A
- Type 1B
- Type 1C
- Type 1D
- Type 1E
- Drive 2
- Type 2A
- Type 2B
- Type 2C
- Type 2D
- Type 2E
- Drive 3
- Type 3A
- Type 3B
- Type 3C
- Type 3D
- Type 3E

Simulated Police Patrol Discomfort Scale (*Drive 1*)

To answer each question place a vertical dash [|] **through** *the corresponding line*

No Discomfort Extreme
Discomfort
Lower Back |————————————————————|

No Discomfort Extreme
Discomfort
Right Shoulder |————————————————————|

Appendix E: Current muscle parameters. Fmax was used to calculate EMG-based total muscle force (Makhsous, 1999; Hogfors *et* al., 1987)

No.	Muscle	Fmax (N)
1	Pectoralis major (upper)	397.7
2	Trapezius (upper)	842.09
3	Deltoid medial	652.95
4	Deltoid posterior	377.49
5	Deltoid anterior	777.83
6	Infraspinatus 1 (upper)	560.54
7	Supraspinatus	277.23
8	Biceps (long)	434.68
9	Triceps (medial head)	878