

Ravindra S. Goonetilleke
Waldemar Karwowski *Editors*

Advances in Physical Ergonomics & Human Factors

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Editors

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Advances in Human Factors and Ergonomics 2018

AHFE 2018 Series Editors

Tareq Z. Ahram, Florida, USA
Waldemar Karwowski, Florida, USA



*9th International Conference on Applied Human Factors and Ergonomics
and the Affiliated Conferences*

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Ergonomics and Human Factors, held on July 21–25, 2018, in Loews Sapphire
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Preface

The discipline of human factors and ergonomics (HF/E) is concerned with the design of products, process, services, and work systems to assure their productive, safe, and satisfying use by people. Physical ergonomics involves the design of working environments to fit human physical abilities. By understanding the constraints and capabilities of the human body and mind, we can design products, services, and environments that are effective, reliable, safe, and comfortable for everyday use. A thorough understanding of the physical characteristics of a wide range of people is essential in the development of consumer products and systems. Human performance data serve as valuable information to designers and help ensure that the final products will fit the targeted population of end users. Mastering physical ergonomics and safety engineering concepts is fundamental to the creation of products and systems that people are able to use, avoidance of stresses, and minimization of the risk for accidents. This book focuses on the advances in the physical HF/E, which are a critical aspect in the design of any human-centered technological system. The ideas and practical solutions described in the book are the outcomes of dedicated research by academics and practitioners aiming to advance theory and practice in this dynamic and all-encompassing discipline. A total of five sections presented in this book:

- I. Ergonomics in Design and Evaluation
- II. Biomechanics, Anthropometry and Posture
- III. Work-Related Musculoskeletal Disorders
- IV. Ergonomic Interventions
- V. Well-Being and Active Aging

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We hope that this book, which is the international state of the art in physical domain of human factors, will be a valuable source of theoretical and applied knowledge enabling human-centered design of variety of products, services, and systems for global markets.

July 2018

Ravindra S. Goonetilleke
Waldemar Karwowski

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Ergonomics in Design and Evaluation



Design Process for an Ergonomic Solution to the Police Duty Belt

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Abstract. Police officers carry various devices on their duty belts for use during patrols. The weight of a loaded belt can range from ~25–35 lbs. Such loading can lead to overexertion and associated injuries (e.g., low back pain) as well as reduced officer performance leading to injuries from violence. In addition, the distribution of the load can compromise officer balance, leading to slips and falls. The objective of this research was to identify design issues with current duty belts and to develop a design framework for police department use in creating custom ergonomic configurations of equipment on a belt. The study was divided into three phases: a literature review, a field study, and design of the ergonomic belt configuration. The resulting design framework for duty belt equipment configuration may serve as a design guideline for police departments and may reduce the incidence of officer musculoskeletal injuries.

Keywords: Occupational safety · Physical ergonomics
Human-centered design

1 Introduction

The duties of law enforcement officers are to serve and protect the public, ensure safety, and avoid personal and department litigation. Officers carry various pieces of equipment on their person to aid them in fulfilling these duties. In addition to their body armor, officers often carry the following items on their duty belt: handcuffs, handgun, ammunition magazines, pepper spray, radio, baton, TASER, gloves, and a flashlight [1, 2]. This equipment is typically selected and issued by law enforcement agencies with each department having different policies on what should be carried. The total weight of all equipment carried at an officer's waist can weigh up to 20 to 30 lbs [2, 3].

Prior occupational safety research [4] has revealed that police officers are more likely to suffer from nonfatal injuries, and experience more days away from work, than all other occupations. The weight of equipment that officers carry on their person has been identified as a contributing factor to these injuries [3]. The weight of the equipment can lead to muscle fatigue and overexertion injuries as well as reduced officer performance, creating the potential for injuries from violence. The combination of the distribution of items on the belt and decreased officer mobility can also lead to slips and falls. Body contact with the duty belt and pressure, in seated postures, may also contribute to cumulative trauma disorders. Considering the nonfatal injuries data for

police officers in 2014, 21.4% suffered from overexertion and bodily reactions, 27% of victim officers suffered from violence and other injuries by persons or animals, 25.3% suffered from falls, trips and slips, and 8.7% suffered from contact with objects and equipment [4]. The prevalence of injuries across officers and a high incidence of low-back pain [5] demonstrate a need to focus on officer safety. Related to this, most officers identify patrol car use and duty belts as origins of back pain [5]. Consequently, there is a need for a solution to reduce negative impacts of duty belt design on officer performance, health and safety.

The objective of this research was to characterize issues with current duty belt design and to develop an ergonomic design guideline for equipment placement on belts. The overarching goal is for enhanced belt design and configuration to reduce the potential for officer physical injuries.

2 Method

The study was broken-down into three phases, including: a literature review, a field study, and design of the ergonomic belt configuration. The literature review focused on police duty belt design and the prevalence of low back pain among officers. The review also identified alternatives to the traditional belt design. The field study was conducted with a university police department in which six “ride-alongs” were performed by researchers with officer on patrol duty across various shifts. Both the literature review and the field study were used as bases for the design process development and the ergonomic belt equipment configuration guideline.

2.1 Literature Review

Researchers have examined the prevalence of specific musculoskeletal diseases and injuries in police officers and have attempted to identify causes. Sprains, strains, tears, soreness and pain account for over 50% of the nonfatal injuries and illnesses, involving days away from work, for law enforcement officers [4]. The duty belt is often identified as a cause of the low-back pain in officers along with patrol vehicle use. Consequently, the literature review focused on low-back pain in police officers, equipment requirements and recommendations for the duty belt, alternatives to the duty belt, and identification of what other studies have done to address the impact duty belts on officer working health. In addition to searching through scholarly databases, police websites were also used as a basis for the literature review.

2.2 Field Study

As part of the field study, we conducted interviews with law enforcement management and experienced officers regarding department policies on duty belt selection, equipment requirements, and equipment layout on the belt. This step in the study was important to understanding police culture and the current state of equipment use and duty belt regulations. Individual precincts control the type of duty belt that officers use as well as most of the equipment carried by an officer. There is some leeway in what the

officers can carry such as the number of handcuffs or the number of non-lethal weapons on a belt. Some departments have recommendations regarding equipment placement on duty belts as opposed to others who allow officers to choose where to place equipment on their belts.

In this phase, we also conducting interviews and observations of law enforcement officers in their daily activities, with a focus on interactions with duty belts. Fourteen officers (33.80 ± 11.58 years) from a university campus police department were questioned about their duty belts, observed in belt use, and asked to complete a questionnaire. The questionnaire included items concerning officer demographics (i.e., age and gender), job experience and training (e.g., did they attend police academy), day-to-day activities (e.g., amount of time spent in a patrol vehicle), and musculoskeletal discomfort experienced on the job. Officers also answered questions directly related to the duty belt, such as the current items attached to their belt, frequency of use of items, satisfaction with the duty belt, issues with current belt design, and any musculoskeletal discomfort associated with belt use. Each officer's duty belt was then examined with the officer describing the current equipment configuration and any issues with the belt design. In addition to the questionnaire and belt review, each individual piece of equipment attached to an officer's belt was weighed in order to understand the biomechanical loading occurring from the belt.

Finally, officers were asked to make subjective ratings of the "life-saving capability" of each item included on a duty belt. A simple Likert scale was modified for this purpose. Officers were also asked to subjectively rate the frequency of use of each item on the duty belt. A modification of a hazard assessment frequency scale was used for this purpose. The ratings from these scales were used as bases for an expected utility analysis to determine the priority of item placement on a belt. The rating scales appear in Table 1.

Table 1. Scales used for expected utility analysis based on the frequency of equipment use and equipment life-saving capability

Rating	Frequency of use	Life-saving capability
5	Frequent/routine occurrence ("daily")	Very likely
4	Likely ("weekly")	Likely
3	Occasional or expected ("happens a few times a year")	Somewhat likely
2	Seldom but not extraordinarily rare (1 in 100)	Unlikely
1	Exceptional/extraordinarily rare ("1 in a million")	Rare

2.3 Design Process

Based on the results of the literature review and field study, a framework was created to enable the design of an ergonomic configuration of duty belts for police officers. As each department provides different equipment to their officers and many officers make decisions regarding which additional equipment will be carried, it is impossible to create a "one-size fits all" solution. The new design framework is intended to help officers and departments in developing balanced belts. Based on frequency of use and

life-saving capabilities, each piece of equipment was assigned a relative expected utility value. This value was used in determining the priority of equipment for positioning on the belt. Beyond this, each of the necessary pieces of equipment were evaluated in terms of physical characteristics (i.e., size, weight, rigidity). The interviews with upper management provided information on where certain equipment must be placed. Furthermore, some equipment must be placed on an officer's non-dominant side to allow for easy access should the handgun be drawn; therefore, accessibility and safety issues were also considered in determining where equipment should be placed. Using all this information, the ergonomic configuration framework was developed with a primary focus on the expected device utility analysis. A primary objective of the configuration was to evenly distribute the weight of equipment across the belt, permit easy access to life-saving equipment, account for frequency of use, and reduce discomfort. An example balanced belt was developed using the framework for the most common equipment carried by a university campus police department, as observed in the field study.

3 Results

3.1 Literature Review

Brown et al. [5] conducted a questionnaire study with active duty police officers from a large Canadian police force in order to assess the prevalence of low-back pain. The researchers found that 54.9% of responding officers had experienced chronic low-back pain since joining a force. The study also found that 75.4% of police officers among the sampled population, who had suffered from low-back pain, believed wearing a duty belt for the entire workday was a contributing factor in their pain. In another study of police in Northern Ireland, Burton et al. [6] found that low-back pain was significantly associated with wearing body armor and a higher number of officer hours in patrol vehicles. Of those police who wore body armor, around 80% believed the equipment to be the main factor in their low-back pain [6].

Nearly every police officer in the United States uses some variation of a duty belt for patrol activities. Most law enforcement agencies supply the duty belt and recommended equipment to officers. Informational resources available through police department websites, as well as printed literature, reveals no standardization as to where officers should place equipment on a duty belt. This situation can lead to imbalances in equipment weight distribution at the belt potentially further exacerbating musculoskeletal issues suffered by officers. Furthermore, an officer might not position equipment in an "optimal" way in order to ensure easy access in life-threatening situations.

With respect to recommendations for belt equipment configuration, officers are advised to avoid placing hard objects (typically handcuffs) at the location of the lumbar spine. In case of a fall, the spine could be injured severely by the handcuffs or similar objects. Handcuffs can also create back pain from constant pressure on the lower back while an officer is sitting in a patrol car. Related to this issue, it is recommended that a soft pouch (i.e., containing latex gloves) be placed on duty belts adjacent to the lumbar

spine [2]. However, these recommendations are among few guidelines or rules for officer belt equipment configuration.

With the considerable weight of the duty belt pressing downward on an officer's hips, constricting the officer's low-back and pressing on sensitive nerves, alternative solutions to the traditional duty belt have been developed. The main alternatives are suspenders and load-bearing vests. However, few agencies use this equipment. The primary reason for lack of use is management not embracing the solutions. Similar to the military, the "sharp" and neat appearance of uniformed officers is of great importance to law enforcement agencies. Some agencies even gone so far as to require that all officers wear their weapons on the right side of the body, regardless of the handedness of the officer. With such culture surrounding tradition and appearance, any major deviation from a traditional uniform appearance is often received with a lack of interest by departments [1].

3.2 Field Study

With respect to musculoskeletal discomfort suffered by police officers, the university campus officers were asked to rate the average discomfort they experienced in different body regions on a regular basis. Figure 1 illustrates the labelling of the body systems and the respective ratings for each region. The back and the hip-thigh region yielded the highest discomfort ratings.

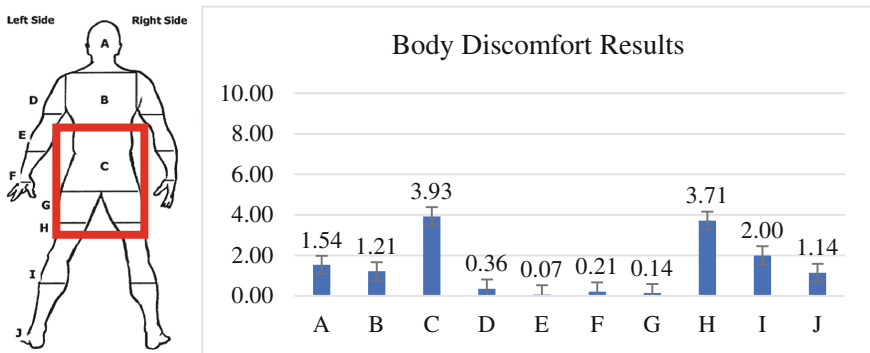


Fig. 1. Body region breakdown and respective average discomfort ratings from survey results.

In addition to the discomfort ratings, officers were asked a variety of open-ended questions. Similar answers were identified and the percentages of officers responding with those answers were determined. Figure 2 presents the responses to the open-ended question, "Do you experience musculoskeletal discomfort from the belt?" Every officer reported experiencing musculoskeletal discomfort from their duty belt with the most common complaints being low-back discomfort/tightness/pain, hip pain/discomfort, and that the equipment "digs" into their legs.

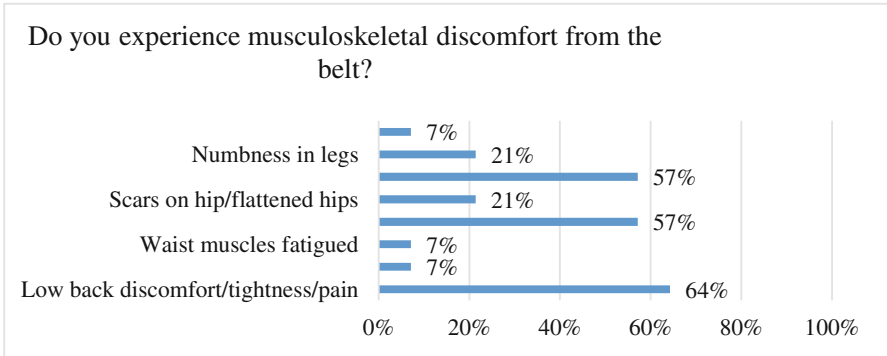


Fig. 2. Responses to the open-ended question on the occurrence of musculoskeletal discomfort with the percentages of officer responses.

Officers were also asked an open-ended question about recommendations they would make for duty belt design and configuration. Figure 3 presents the results to the question “What recommendations do you have to improve your current belt?”

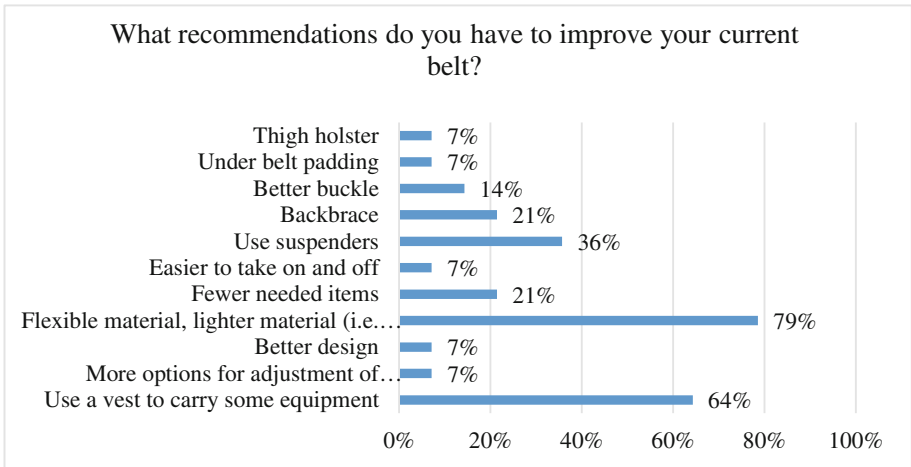


Fig. 3. Responses to the open-ended question current belt improvements with the percentages of officer responses.

In addition to the questions on musculoskeletal discomfort and belt recommendations, officers were asked a series of questions about the equipment on their duty belts. Appendix presents the responses officers gave regarding their rationale for where they placed each piece of equipment on their duty belt. The officers were also asked to rate their frequency of use and perceived life-saving capability for each piece of equipment. Using the officers’ ratings, the expected utility of each piece of equipment was calculated using Eq. 1.

$$\text{Frequency of use rating} * \text{Life-saving capability rating} = \text{Expected Utility} \quad (1)$$

The pieces of equipment were subsequently ordered according to expected utility value from greatest to smallest and assigned a priority number. Table 2 shows the mean for the frequency of use ratings and the life-saving capability ratings to determine the expected utility value.

Table 2. Results of the equipment specific questions regarding frequency of use ratings and life-saving capability ratings with the subsequent calculated expected utility value.

Priority number	Equipment	Frequency of use rating	Life-saving capability rating	Expected utility
1	Radio	5.0	4.9	24.3
2	Flashlight	4.6	4.7	21.3
3	Gloves	4.0	4.4	17.6
4	Handcuffs	3.9	3.9	15.0
5	Gun	2.8	5.0	13.9
6	Magazines	1.8	4.9	8.6
7	Baton	1.3	3.2	4.1
8	Taser	1.2	2.8	3.3
9	OC Spray	1.5	1.3	1.9

3.3 Design Process

On the basis of the results from the first two phases of the research, we developed a flowchart of considerations to be made in duty belt equipment configuration. The flowchart is presented in Fig. 4 and is intended to serve as a guide for officers in developing an ergonomic configuration of duty belt equipment. An officer applies this

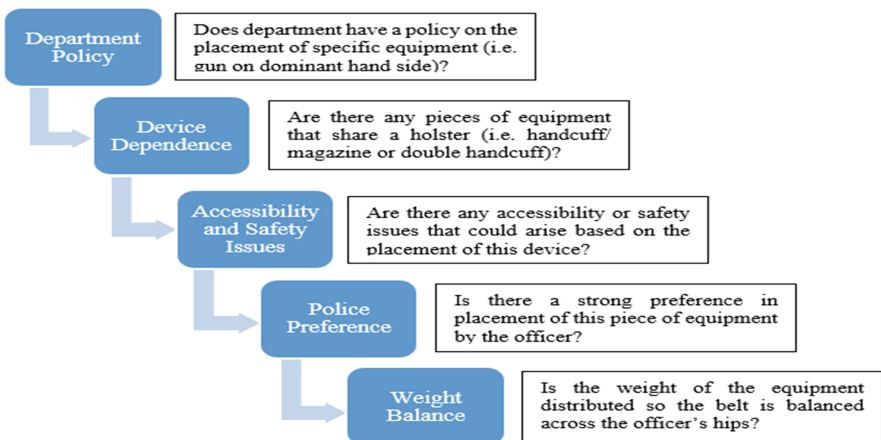


Fig. 4. Process flowchart for developing an ergonomic belt configuration.

flow process to each piece of equipment to be mounted on the duty belt in order of priority number (or based on the expected device utility value). The process yields a location for each item.

The officer first needs to decide what equipment will be placed on the belt. Different departments have different requirements on what must be carried. Once the officer decides on the equipment inventory and holsters, (s)he proceeds to the first step in the flow chart focusing on consideration of department policies. The gun would typically be the first item on an equipment list to which a department policy would apply, specifically placement on the dominant side. Consequently, the gun would be placed first and the weight of the device and its holster would be added to the dominant side. Many departments have policies that a taser must be placed on the non-dominant side to allow for cross-draw of the device. The taser and its holster weight would be added to the non-dominant side of the belt. Once all items with an applicable department policy have been positioned, the officer would move to the next step in the flow process.

In the second step, the officer would note if they have any joint holsters, such as a dual handcuff case or a joint magazine/handcuff case. If so, the objects would be paired together in the remaining equipment list. For instance, if a joint handcuff and magazine case is used, the item with the lower priority number would be placed on the list next to the one with the higher number so the magazines would move up the list to join the handcuffs.

An example of the entire process for the equipment carried by the campus police department is shown in Fig. 5. The items that were positioned on the duty belt in each phase appear with a “check mark” next to them and the remaining equipment items

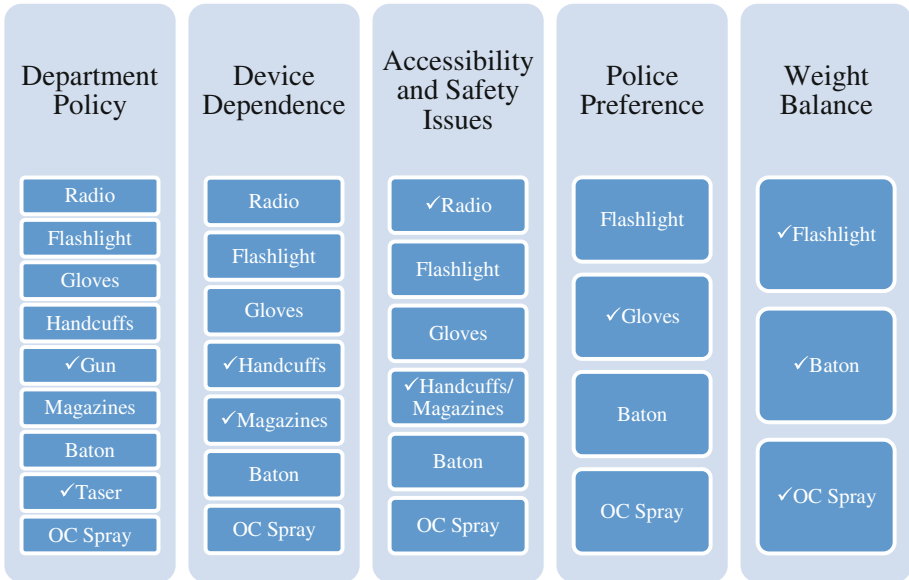


Fig. 5. Process phases in which each device achieve placement on a belt (see check marks).

Table 3. Common belt equipment list, recommend device location and justification.

Equipment		Rationale	Location
1	Gun	Department policy must go on dominant side	Dominant side
2	Taser	Department policy must go on non-dominant side to prevent confusion with the gun	Non-dominant side
3	Radio	For safety reasons, officers keep their radio on their non-dominant side to call for help if their weapon is drawn	Non-dominant side
4	Handcuffs/Magazines	For accessibility, the magazines go on the nondominant side for the officer to be able to reload their weapon using their non-dominant hand with the weapon drawn	Non-dominant side
5	Gloves	As they do not take up much space and can provide extra cushion for the lumbar spine, most officers wear the glove pouch in the center of their back	Center of the back
6	Flashlight	Some officers have a preference, but there is no consensus on where this item should be place. It is often placed on the dominant side to balance the weight	Dominant side
7	Baton	Some officers have a preference, but there is no consensus on where this item goes. It is often placed on the dominant side to balance weight	Dominant side
8	OC Spray	Most officers limit use of spray because it often impacts them as well. This item is typically placed where there was space on the belt and to balance weight	Dominant side

passed to the next phase for further evaluation. The placement of each device and rationale are detailed in the Table 3.

4 Discussion

The purpose of this study was to review relevant literature and conduct a field study as a basis for developing a design framework to facilitate ergonomic configuration of equipment on police duty belts. In regard to the literature review, the occupation of police officer was reported to have high incidence of low-back pain with officers perceiving the duty belt and patrol vehicle use as causes of discomfort. Many studies have attempted to identify the origins of low-back pain as well as common occupational risk factors. Adams and Dolan [7] contended that mechanical body fatigue may be a cause of low-back pain. Other risk factors have been identified to include heavy or repeated lifting [8] and awkward movements or postures [9]. Furthermore, driving has been shown to be associated with symptoms of low-back pain and represents an

increased health risk for the spine [10]. While there is limited research on the effects of load carriage on police officers, there is an abundance of research regarding load carriage on the body of soldiers. Military research illustrates the impact of load carriage and body armor on the biomechanics of the soldier and soldier performance. Related to this, falls or near falls are the leading cause of hospitalization for soldiers with events often occurring while negotiating obstacles (e.g., stairs, curbs, and other heights). Soldier trips and falls are exacerbated by the load soldiers carry [11]. The findings of this research are applicable for understanding the potential impact of load carriage on police officers and could provide another basis for formulating design recommendations for police duty belt design and equipment configuration. The military literature illustrates the importance of balancing load carriage for an individual to reduce body pain and the likelihood of falls and associated injuries. Unfortunately, the literature also revealed a lack of consensus on the placement of equipment on the police duty belt. In addition, alternative mechanisms to relocate some items from the duty belt to other areas of the body are often rejected by departments. The literature revealed that many departments favor a traditional, non-militaristic appearance and are reluctant to adopt, for example, load bearing vests.

The results of our field study confirmed the findings of the literature review. From the questionnaires and ride-alongs, we observed high incidence of low-back and hip pain among campus police officers. This information and subjective ratings of equipment utility allowed each belt-mounted device to be given a priority number that can be used in sequencing device placement on a belt. In addition, observations made on officer belt configurations and their rationales for device placement were recorded as bases for identifying general potential locations of devices. For instance, all officers agreed that the radio should go on the non-dominant side to allow for access to call for help when the officer has their gun drawn. However, for many items, like the baton and flashlight, there was no consensus among officers regarding placement with some officers noting that they placed the items according to instruction as part of basic law enforcement training or just where the devices would fit on a belt.

With each department opting for different equipment and with different policies regarding what equipment is required for carry, a general consensus on duty belt equipment configuration is unlikely. The campus police department, which was surveyed as part of this study, generally stipulates that officers are to carry every item for which they have received training. However, many of the officers in this department chose to only carry one set of handcuffs (vs. two) as they do not regularly arresting people on a college campus. The officers often elect to carry a dual magazine/handcuff case. As another case, a local city police department near the campus police department only requires that officers carry two nonlethal weapons on their duty belts, including the taser and either the baton or the OC spray. Officers in this department often carry two sets of handcuffs as they arrest people on a more regular basis and often have a need for a second pair.

With these departmental and individual preferences in mind, the duty belt design framework needed to be general enough, such that it could be applied across departments and officers, while still supporting ergonomic belt equipment configuration. Consequently, multiple design factor considerations were identified in the flow process, including department policies, device dependencies, equipment access and safety

issues, officer preferences and the resulting weight and balance of a fully configured belt. The design framework requires that each piece of equipment be evaluated in terms of all design factors. The objective is to ensure that officers achieve a safe and healthful configuration of all the equipment provided by a department as well as officer personal choices or preferences on equipment (e.g., more than one set of handcuffs).

5 Conclusion

A literature review and field study were used as a basis for developing a design framework for police officers to use in developing ergonomic configurations of equipment placement on duty belts. With a high prevalence of low-back pain among police officers and a lack of standardization of equipment placement on belts, duty belt equipment and weight are often identified as sources of low-back pain. The new design framework is expected to aid officers in appropriate equipment configuration across a belt and balancing of belt weight. A balanced belt configuration is expected to reduce the potential for low-back pain in addition to reducing the probability of slips and falls attributable to imbalanced belts.

One limitation of this study is that only one campus police department was observed in the field study. The methodology should be verified with additional departments. Modifications to the design framework should be made if additional rationales are provided for equipment placement, particularly those relating to safety and accessibility issues. A limitation associated with implementation of the new design framework is application may only be effective for new officers and initial belt configuration. Changing the belt configuration of more senior and experienced officers can pose a safety risk as they likely have developed muscle memory for a particular belt configuration.

We plan to conduct future research to validate the framework with officers in other police departments. In addition, balanced belt configurations will be compared with commonly used belt layouts in simulated foot patrol activities in order to determine the biomechanical advantage (if any) of ergonomic belt configurations.

Acknowledgments. This study was funded by a pilot grant from the National Institute of Occupational Safety and Health, Southeastern Education and Research Center.

Appendix: Equipment Placement Comments

General	“Place equipment with restraints or locking mechanism towards the front because it is harder for an attacker to grab my baton when he has to reach behind me”
	“Arrange my equipment for comfort and ease of access-being able to access all equipment without looking. I wear my belt tight so items don’t move and always in the same place, so I can get what I need without looking or thinking”
	“My waist is too small to fit everything. So I do not carry everything”
	“All weapons on dominant side”
	“I place things based on my training”
	“Places nothing on my back to avoid falling on it and leaning on it when in the patrol vehicle”
Gun	“Placed on dominant hand side per department policy”
Radio	“Non-dominant side in order to communicate if gun is drawn”
Baton	“Place my baton on my dominant hand side”
	“Place my baton on my non-dominant side so I can cross-draw and expand as I pull it with my dominant hand”
Flashlight	“Placed on non-dominant hand side so I can draw it while I also have my gun drawn”
Magazines	“Place such that the non-dominant hand can grab and reload the gun held in the dominant hand”
OC Spray	“I put it where I have room”
	“I do not carry the spray anymore because I will never use it. I always get some in my eyes when I use it”
Taser	“Per department policy is placed on the non-dominant side to allow for cross-draw.” (do not put TASER and gun on same side as it could lead officer to grab the wrong weapon)
	“I am ambidextrous. My gun goes on my right side and my TASER uses a lefty holster on my left. If a weapon is in my right hand then I know it’s my gun, and in my left hand, then I know it’s the TASER”
	“I angle the TASER as much as I can to avoid it digging into my leg”
	“I do not carry the TASER because I have no room for it”
	“I do not carry a TASER because it digs into my leg when I sit down and I never use it”
Handcuffs	“Place on non-dominant hand to allow for gun to be drawn. Was trained at BLET (or police academy) to handcuff with their non-dominant hand”
	“Quit carrying an extra set of handcuffs because never used them, and injured myself when I fell on them”
Gloves	“I put it in the center of my back as it fits nicely there”
	“The gloves are kept in my pocket, not on my belt”
	“I put the glove case upside down in the center of my back to avoid it unbuttoning every time I sit down”

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Effects of Body Armor Fit on Warfighter Mobility as Measured by Range of Motion (ROM)

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Abstract. This study focuses on the effect of body armor fit on Warfighter mobility as measured by range of motion. Forty male active duty military personnel participated in the study with four different body armor configurations: Baseline, Initial Fit, Increased and Decreased sizes. The results indicated that the degradations in the Decreased and Initial Fit sizes were always statistically equivalent to each other, however, mobility in the Increased size were further degraded; 5° for the extension and rotation movements on average and up to 1 inch for flexion and reach. More importantly, across all the movements while wearing an Increased size further degraded mobility by 2.4% on average relative to the Decreased or Initial fit size. Therefore, when evaluated by ROM measurements, there was no benefit to wearing a smaller body armor size to improve mobility relative to the Initial Fit size, but there was a penalty wearing an Increased size.

Keywords: Body armor · Encumbered Anthropometry · Military Protection · Range of motion · Warfighter mobility

1 Introduction

Body armor systems provide essential ballistic protection for military personnel. However, it has been documented that body armor, a type of protective equipment, can also interfere with a Warfighters' mobility [1]. The immediate changes identified from wearing protective equipment on the Warfighter include an increase in bulk and reduced mobility related to the equipment [2, 3]. Thus, a clear understanding of the relationship between mobility and the size and fit of that body armor system is critical to being able to better discern how protective equipment can influence mission success.

Standardized encumbered range of motion (ROM) measurements [1] were used to help quantify a Warfighter's mobility in this study. ROM is a quantitative and controlled measurement of individual joint movements in a single plane of motion, focusing on the major joints, in this case the shoulders, hips, and spine; all areas covered by the body armor systems. By comparing measurements in one configuration

to another configuration, the effects of different conditions on individual mobility can be quantitatively represented.

For this study, three consecutive sizes (an initial predicted size along with two adjacent sizes) were compared to one another to investigate the effect of body armor fit on mobility as measured by ROM measurements. This study is a part of a larger project that investigated the relationship among anthropometric variability, body armor fit, and mobility and performance, with a goal of improving body armor design for increased mobility, protection and functionality. Effects of body armor fit on performance as measured by marksmanship tasks was previously published [4]. The current study examines the effect of body armor fit on Warfighter mobility when measured by ROM measurements focusing on two research questions: (1) How does wearing body armor affect Warfighters' mobility? and (2) What is the effect of body armor fit on Warfighters' mobility?

2 Method¹

2.1 Test Item

This study used the Generation III Improved Outer Tactical Vest (IOTV) configured with soft armor for front, back, yoke and collar and with hard plates on the front, back and sides (Fig. 1). Since the scope of this study was to understand overall torso protection, the deltoid, groin and lower back protective accessories were not included.



Fig. 1. Improved Outer Tactical Vest (IOTV) Gen III (Photo courtesy [4])

2.2 Test Participants (TPs)

Human Research Volunteers (HRVs) participated in this study. HRVs are active duty U.S. Army military personnel recruited to come to Natick Soldier Research

¹ Method Sects. 2.1, 2.2, 2.3, 2.4 and 2.5 are identical to the sections in the paper “Effects of Body Armor Fit on Encumbered Anthropometry Relative to Bulk and Coverage by Choi, Garlie, and Mitchell” since both papers are subsection of the same study.