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# Designing a Human-Centric Rigid Body Armor for Female Police Officers: The Implications of Fit on Performance and Gender Inclusivity

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Designing a Human-Centric Rigid Body Armor for Female Police Officers:  
The Implications of Fit on Performance and Gender Inclusivity

A thesis submitted in partial fulfillment  
of the requirements for the degree of  
Master of Science in Human Environmental Sciences  
with a concentration in Apparel Merchandising and Product Development

by

Sarah West  
University of Arkansas  
Bachelor of Science in Apparel Merchandising and Product Development, 2017

May 2019  
University of Arkansas

This thesis is approved for recommendation to the Graduate Council.

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## **Abstract**

The lack of availability of female plates for police officers is an issue that has not been analyzed. Female anthropometry is uniformly different from male anthropometry. Currently available hard plates are flat. These plates may decrease coverage while increasing feelings of poor fit, discomfort, and poor mobility for both male and female officers. The plates designed for males offer the possibility of female officers experiencing feelings of gender exclusion. This research project explored the current perceptions of male and female police officers in Arkansas across the dimensions of fit, comfort, and mobility in the context of hard plate body armor. Perceptions of gender exclusion were explored through a gender ostracism scale. A female police officer of the population was the subject of a case study which explored the influence of a prototype plate from a 3D body scan on perceptions of fit, comfort, mobility, coverage, and inclusion. Range of motion was evaluated through goniometer measurements and perceptions were evaluated through Likert-scale responses and open-ended response. The outcomes of the research project included a proposed methodology for the development and evaluation of 3D modelled prototype plates.

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## **Dedication**

I would like to dedicate this research to my son Roland. My hope is that he always pursues to improve the world, and respect and honor those who serve and protect.

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## List of Published Papers

1. Police officer attitudes and beliefs on gender ostracism and occupational equipment. Chapter 1. Submitted for review to *Police Practice and Research*.
2. Evaluation of design criteria and development of a prototype hard plate for female police officers based on 3D modelling: A case study. Chapter 2. Submitted for review to *International Journal of Fashion Design, Technology, and Education*.



## **I. Introduction**

A two-part research project was completed and formatted for publication in two different journals. The first part of the research was a survey of Arkansas police officers' perceptions of gender ostracism and occupational equipment. This study was submitted to *Police Practice and Research* for consideration. The survey included an invitation to female police officers to participate in 3D body scanning and mobility testing. For the second part of the research project, one female officer became the single subject of a case study to develop a methodology for designing prototype plates. The officer then gave feedback on 3D printed versions of the prototype plates. A description of the design criteria, the necessity of form-fitting plates, the potential impact of gender inclusive equipment, and the female officer's perceptions of the prototype plates from this research project compared to currently available plates was prepared as a manuscript and submitted to the *International Journal of Fashion Design, Technology, and Education* for consideration.

### **Background**

Body armor, through uniform policy, is the most effective way to reduce officer fatalities. In 2017, all but seven officers that were killed while wearing body armor were shot somewhere other than where their body armor would protect (Federal Bureau of Investigation, 2017). Between 2008 and 2017, only 1.6 percent of total firearm assaults resulted in officer fatalities for officers wearing body armor. Cities with populations higher than one million have the most incidents of armed and violent crimes, where body armor is necessary for officer safety. Cities with populations higher than one million also employ the highest percentage of female officers. There are roughly 83,784 female sworn police officers in the United States as of 2017. This represents about 12% of all active duty officers. Arkansas is below that average, with females

constituting 9.5% of officers (FBI, 2017). The lower percentage of female officers should be explored in the context of belonging and perceptions of ostracism. Despite the disparate ratio of male to female officers, there are tens of thousands of female officers in the United States, 567 in Arkansas, that face ostracism that extends to the equipment available to them.

Male and female police officers may only be provided soft armor vests by their departments, and often must find their own hard plate armor. The resources available through the National Institute of Justice let users search for compliant armor according to company, side, front, or back opening, threat level, and gender. When the filter of female is applied along with threat levels III and IV, which are the only threat levels at which insert hard plates may be tested for compliance, there are no products available. There are vests and flexible armor designed for females currently available, but hard plates are not available for female body shapes. Hard plate inserts are designed to sit flat on the chest. The hard plate armor available for police officers fits female bodies in such a way that extra space is exposed at the chest as breast tissue pushes the flat plate away. This exposes vital organs and increases the possibility of a fatal shot. Not only is this a safety concern, but the unavailability of plates designed specifically for women may decrease their perceptions of belonging in the career and increase feelings of ostracism.

### **Problem Statement**

The hard plate ballistic equipment available for officers that comply with the standards of the NIJ are either male or unisex. This means that there is not equipment available specifically for females despite equipment designed specifically for males being available. Hard plates for the chest that are available are mostly flat, which is a design feature that caters to male anatomy. A lack of plates designed to fit the female anatomy is a detriment to female officer inclusion. It is critical that a hard plate compliant with the ballistic standards of the National Institute of Justice

and designed for women is made available. The potential need, possible outcomes, and design criteria will be explored in this study.

A hard plate designed specifically for female police officers that complies with the National Institute of Justice is not available. The implications of this should be explored in the context of performance, safety, and inclusion. The need for hard plates for females must be addressed. Hard plates are the most effective equipment for reducing police officer fatality from ballistic shots. Female anatomy compromises the effectiveness of flat plates. The anatomical incompatibility reduces coverage and may cause discomfort which then may reduce performance. A plate developed based on 3D data from body scans has the potential to reduce inhibitors to coverage, comfort, and mobility. The 3D data can be used to create 3D models of prototype plates. The models can then be 3D printed and worn by officers to assess the viability of a form fitting plate for females.

The purpose of this study will be twofold. The first component of the study will be the evaluation of perceptions of currently available body armor systems from both male and female officers. The responses of male and female officers will be compared to investigate whether gender influences perceptions of discomfort while wearing hard plates, as well as feelings of ostracism. Secondly, a methodology for designing and evaluating prototype plates will be proposed. Design criteria for hard plate body armor optimized for female body shape will be developed into a prototype plate using a single subject's 3D body scan. A protocol for evaluating the impact of ergonomic design on comfort, fit, and mobility, and the necessity of gender inclusive armor will be presented based on the development and fit trial of the prototype plate.

## II. Literature Review

The National Institute of Justice performs testing of ballistic equipment, including hard armor plates. Testing procedures focus on the size and protection level of plates. Size restrictions and ballistic protection are detailed and regulated by the National Institute of Justice. The obligation of testing female plates for use by police officers in the United States would belong solely to the National Institute of Justice. However, research and development of body armor has been completed either in congruity with or independent of the National Institute of Justice.

### *Gender and Performance*

Gender is a predictor of difference in mobility while wearing ballistic vests (Domina, Kyoung An, & Kinnicutt, 2016). Physiological performance differences between male and female officers in general are minimal. When subjects were asked to perform a physical battery while wearing ballistic vests following treadmill exercise, blood oxygen, heart rate, and respiratory rate were not correlated to gender (Riccardi, 2007). However, women did report a greater perceived increase in physical exertion when wearing body armor compared to not wearing body armor. A possible reason for this is a difference in the way male and female bodies respond to increased load carriage. In a study by Ling (2004), women were shown to have a similar load carriage performance to men, but their posture differed to compensate for upper extremity weakness. The women can hyperextend their neck and pull their shoulders forward to replace the weight onto their hips. The study found that a properly fit hip belt might help distribute weight and minimize shoulder and pelvic discomfort.

Range of motion is important for performance and comfort, which are restricted for females by common unisex ballistic vests (Kyoung An, 2010). Female officers experience a constant pressure at the bust which male officers do not. Despite this, general discomfort is

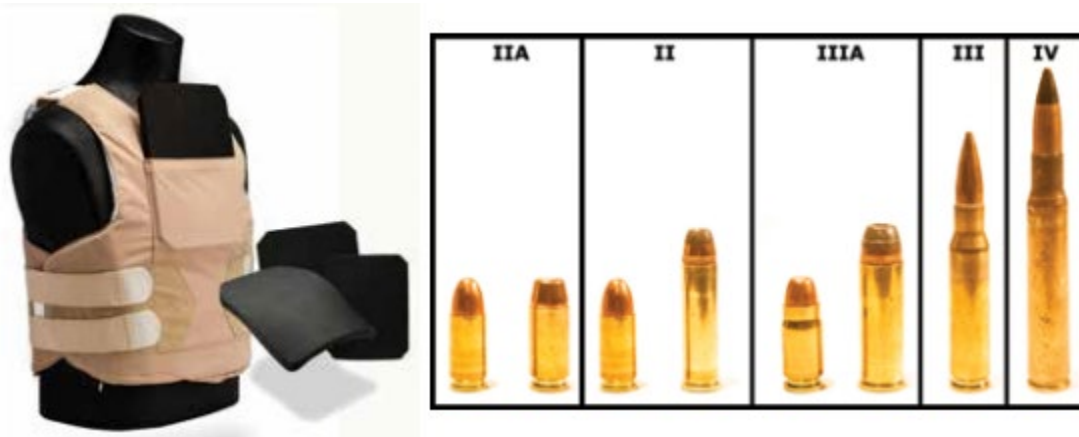
similar for men and women. One of the highest reported factors of discomfort for officers is thermal (Grant et al., 2010). Armor and plates do not have a statistically significant influence on water evaporation, such as the ability for sweat to cool the body (Domina et al., 2016). In fact, physical fitness appears to be the most significant factor in ballistic vest thermal comfort; not gender. This means that the discomfort female officers feel would not be from physiological performances differences from men, such as weakness or body fat percentage, but rather anthropometrical fit (figure 1). Female officers have shown a desire for contoured vests, which they believe would give them more comfort and better protection (Mahbub, 2015). Adjustments to the chest, neckline, armhole, and plate shape of ballistic vests may improve range of motion and performance for female officers. The chest should be less tight with a plate that is not flat. A flat plate is offset by breast tissue; up to 3 inches for an officer with a C cup sized bust (Tung, 2008). Contoured ballistic vests have been explored using knit and angle-interlock seamless vests, but contoured plates for the female body have not been effectively explored (Mahbub, 2015; Chen & Yang, 2010).



*Figure 1.* Example of fit issues for female police officers. Note exposed area caused by breast tissue (ASTM, 2015).

## ***Body Armor***

Body armor in reference to law enforcement in the United States describes ballistic resistant apparel and equipment worn by law enforcement officials. In a national study performed through the Bureau of Justice Statistics, 71% of local police departments required protective body armor to be worn while in uniform in their policies and procedures. The presence of this requirement was positively correlated with the population of residents the department served (Reaves, 2013). Soft body armor vests are made of ultra-strong fibers such as polyaramid plastic or extended-chain polyethylene. Popular trademark names of these fibers include Kevlar and Spectra. Protection levels of soft armor are referred to as Type IIA, Type II, and Type IIIA in order of increasing ballistic resistance (figure 2). These vests are useful to catch fragmentation and direct fire from relatively low mass and low velocity bullets. Bullets such as 9 mm, .357 Magnum, and .44 Semi-Jacketed Hollow Point with a velocity below 1370 feet per second are relatively low mass and low velocity compared to those fired from assault rifles, such as 7.62 mm Full Metal Jacket bullets, also known as M80 bullets.



*Figure 2.* Flat hard plate with compatible vest and ballistic protection levels by projectile (NIJ, 2008).

The National Institute of Justice (Rice, Riley, & Forster, 2008) requires armor plates classified as Type III and Type IV to catch M80 bullets with a velocity up to 2810 feet per second and 2910 feet per second, respectively. These plates are known as hard armor or hard plates. Steel was the original material used in these plates, followed by plates composed of extra thick Kevlar; but ceramic is becoming increasingly more common because of its light weight and chemical properties (Military Technology, 2006). The inorganic, crystalline ceramic breaks the bullet while the vest in which the plate is inserted catches the fragmentation from this event.

The Federal Bureau of Investigation keeps a database of Law Enforcement Officers Killed and Assaulted (LEOKA) which offers a nearly complete sample of officers in the United States because of high participation, although reporting is not required. This database was used for a study of the effectiveness of body armor which found that wearing body armor reduces the risk of being killed from a torso shot by a factor of 3.4 and does not significantly affect the probability of being shot or a shot being aimed at the torso (LaTourette, 2010). In the same study, an analysis of fatal torso shots taken while an officer was wearing body armor between 2004 and 2007 revealed that only about 1 in 5 fatalities were due to penetration. The remaining shots were fired through the arm or shoulder (35%), between hard plate panels (19%), above the vest (16%), or below the vest (8%). Researchers concluded that body area coverage is a more limiting weakness than penetration level and that providing body armor to all police in the United States would save 8.5 lives a year which, at the time of the study in 2010, would be an economical benefit twice the cost. Both soft body armor vests and hard armor reduce pulmonary injury from blast pressure (Wood et al., 2013). Body armor is significant and economically imperative life-saving equipment which could be improved by increasing coverage and advancing body armor technology to be more comfortable and lightweight (James, 2016).

Body armor that is comfortable and lightweight can improve performance and increase the likelihood that police officers will wear their equipment. In a study through the Police Executive Research Forum, 90% of police officers considered body armor “critical for their safety” (Grant et al., 2012). The officers surveyed expressed nearly equal importance of protection level (75%) and comfort (70.5%) when selecting body armor, and participants suggested improved comfort (84.8%) and improved fit (72.6%) more frequently than improved protection (62.4%). Only 58% of officers were satisfied with the fit of their body armor, often correlating with the presence of manufacturer and agency fittings. Other suggestions included improved coverage and improved fit specifically for women. An increase in mandatory wear policies within law enforcement agencies as determined by the Grant et al. (2012) study means more police officers will be required to wear body armor, and the need for comfortable body armor will increase as well.

### ***3D Modelling***

3D body scans can be manipulated as 3D objects. A 3D object file has information for the X, Y, and Z axis, similarly to a body scan mesh. Whereas a 3D body scan is a collection of triangles which have corners at points in a point cloud, 3D objects may have faces of any shape with corners meeting at a vertex. Vertices are connected by edges, which are straight lines running the shortest distance possible between the vertices. Edges which connect to complete a shape create a face. A cube is a simple example of a 3D object with 6 faces. In 3D modeling software, vertices, edges, and faces can be manipulated and transformed. A 3D object within 3D modeling software may be referred to as a mesh. Complex meshes will need to be cleaned to react to modification correctly. Registration is cleaning and preparing a body scan for analysis. Cleaning a mesh includes deleting vertices that are duplicates, recalculating normals or



converting faces to all be facing inward or outward and filling holes or creating faces where edges complete a shape but the mesh has not filled in a face. Once a mesh is cleaned and repaired, it can be printed on a 3D printer.

### ***3D Printing***

Printing an object in 3D is done using filament. The process is similar to printing in 2D using ink. The file being printed is converted to a format that the printer can process, and the materials are extruded from the printing head. Filament is most often a tubular plastic feed that is heated by the printing head to extrude thinly and malleably. The plastic in filament may be Acrylonitrile Butadiene Styrene (ABS) or Polylactic Acid (PLA). Materials such as carbon or wood have also been used in filament. The filament is stacked from the base plate in layers. Each layer sits on the previously printed layer as the base plate lowers and the printing head moves back, forward, left, or right. If there is a part of the object which overhangs and does not have a previously printed layer to sit on, the 3D model must be prepared for printing to have supports. Supports in 3D printing will print as the model does, but with less fill and detail, just so that an overhanging part of the object can print without falling. Objects can be set to have a solid fill, where the printing material exists at full density throughout the print. This is not often necessary. Print objects will usually be printed with a lower fill density, such as 20%, and a lattice-like support network will print inside of the object. The layers will appear similar to a waffle as they are printing because of this. The outermost filament on a print is referred to as the shell, and the thickness of this shell can be adjusted. The shell of a print will take longer to print as the printing head moves slower to improve the detail and evenness of the filament.

3D printing has applications in several fields, including medicine and engineering (Gross, Erkal, Lockwood, Chen, & Spence, 2014; Hockday et. al, 2012). The applications of 3D printing

in the apparel industry expands from trims design to full garment printing (Yap & Yeong, 2014). Buttons, zippers, connectors, intricate embellishments, and fabrics can be created through fused deposition modeling (FDM). FDM is the type of 3D printing described above. Selective laser sintering (SLS) is a form of 3D model production that needs no support as the model is solidified with high powered laser beams directed into a vat of powder at points where the model will be formed. SLS allows for entire garments to be printed as a single object. 3D printing allows for very high customization. A design that the end user will wear can be created directly from a mesh of the end user's 3D body scan. The application of 3D printing to highly customized occupational equipment for female officers would be the most current and effective strategy to enhance fit.

### **Hypotheses**

H<sub>1</sub>: Female officers have lower perceptions than male officers of comfort, fit, and mobility in the currently available hard plates.

H<sub>2</sub>: Female officers have greater perceptions of ostracism than male officers.

### **Research Objectives**

1. To explore design criteria for form fitting hard plates for female officers.
2. To develop a methodology to create form fitting plates based on a body scan.
3. To develop a protocol to:
  - a. Compare currently available hard plates and a prototype plate in the context of range of motion and coverage for female officers.
  - b. Evaluate female officers' perceptions of fit, comfort, and mobility while wearing the prototype plate.
  - c. Evaluate the potential impact of the prototype plate on female officers' feelings of inclusion.

### **III. Chapter 1: Police officer attitudes and beliefs on gender ostracism and occupational equipment**

#### **Abstract**

Police officers in the United States wear ballistic body armour. This armour is available as soft vests and inserts as well as hard inserts. The hard inserts were initially designed for males and are mostly flat. A survey on body armour and gender ostracism was distributed to officers in police departments across a mid-south US state. All officers who responded expressed some dissatisfaction with armour, especially hard armour. Male officers unexpectedly reported more dissatisfaction than females in the categories of fit and comfort. Male and female officers reported similar experiences in issues of mobility. Female officers also expressed a belief that police equipment is not designed for them. Female officers reported higher levels of gender ostracism than males. The female officers in this study indicated there may be a connection between higher perceptions of gender ostracism and a lack of hard armour for females.

#### **Introduction**

Body armour systems are essential to police officers' safety; however, the improvement of the fit of these body armour systems is paramount. Restricted mobility and discomfort are two primary consequences of poor fit with currently available body armour systems. Both male and female officers reported dissatisfaction with their body armour systems, although female officers reported higher levels of discomfort and restricted mobility (Grant et al., 2012). Female officers also report strong feelings of ostracism in the workplace, compounded by the lack of available equipment designed for their anthropometry (Harper, 2016). The perceptions of poor fit, discomfort, and poor mobility female officers experience with their body armour systems likely contribute to feelings of exclusion. Yu (2018) emphasizes that feelings of exclusion may contribute to an unrepresentative distribution of police officers. The percentage of female

officers in Arkansas is the median for states in the United States, with the distribution of female officers not exceptionally low or high (FBI, 2017). In this study, experiences of male and female officers are compared in the context of body armour systems as well as feelings of ostracism based on gender.

## **Background**

### ***Body Armor and Performance***

Studies on body armour and its influence on performance have shown that hard plates and soft armour body armour systems impact subjects through increased workload, decreased work capacity, decreased speed of task completion, and decreased balance and stability (Tomes, Orr, & Pope, 2017). Dempsey, Handcock, and Rehner (2013) tested subjects wearing body armour and equipment and found that balance disturbance is the main inhibitor of performance. Wearing body armour limits mobility, which then restricts officers' ability to compensate for the load they are carrying. Limited mobility coincided with physiological cost in the form of up to a 16% performance reduction. Body armour restricted mobility up to 42%. Restricted movement in body armour can also have a negative impact on the wearer's comfort. Subjects in one study were given the task to maintain marksmanship while performing various tasks wearing three different body armour load configurations in rested and fatigued states. There were no changes in lethality, precision, accuracy, aiming time, or time spent on each target (Brown, McNamara, & Mitchell, 2017). The body armour configuration with the most coverage only slowed subjects down when trying to detect, locate, and move between targets and when changing from standing to prone. This shows that body armour does not inhibit motor skills, regardless of whether the subject is rested or fatigued. Body armour inhibits performance, not skills. This indicates the influence of body armour on performance is a physical inhibition.

Police officers and soldiers use the same types of body armour. Soldiers have perceived body armour as a primary aggravator of pain and discomfort. Soldiers deployed in Operation Iraqi Freedom experienced pain in the back, neck, and upper extremities directly and positively correlated with the length of time they wore body armour during the day (Konitzer, Fargo, Brininger, & Reed, 2008). A positive relationship between ballistic vest fit and clothing comfort was established by Barker and Black (2009). In a jump test by Lee, Hong, Kim, and Lee (2013), a fitted vest was shown to reduce pressure and impact on the shoulders, and user perceptions were positive toward a fitted vest as well. Concealed body armour was found by Close, Carruth, Babski-Reeves, Blackledge, and Wilhelm (2009) to be preferred for design. Subjects perceived a design closer to the body as less bulky and less restricting on their range of motion. A comparison of mechanical assessment of body armour systems and wearer trials showed that the wearability and comfort of body armour is not based on flexibility or coverage, but rather correct fitting that moves with the body of the wearer (Horsfall, Champion, & Watson, 2005). The relationship between fit, comfort, and mobility perceptions of body armour wearers has shown to be strong, in that fit, comfort, and mobility are indicative of each other.

### ***Female Police Officers***

Law enforcement should be representative of the population it serves, and there remains a critical need for an increase in female officers (Yu, 2018). The workplace of police departments is male-dominated and often oppressive to female officers (Chen, 2015). Female officers have expressed perceived pressure to work harder than male officers to receive the same rewards and recognition, to assimilate into policies that are not inclusive for their gender, and to prove their competence and worth repeatedly, specifically because of their gender (Chen, 2015; Harper, 2016). Police work is a dangerous career path that puts very similar occupational stress on

officers regardless of gender (McCarty, Zhao, & Garland, 2007). This stress is compounded with the pressure felt by female officers.

Despite female officers' expectations and acceptance of condescension and sexual harassment from male co-workers, the gender barrier has shown to be irrelevant to officers' decision to remain in their careers in one study (Seklecki & Paynich, 2007). Harper (2016) found that female officers showed extreme distress towards police equipment designed for men, with one subject recounting a superior officer telling her "if you have a man's job, you will wear a man's clothes" and other subjects elaborating a general feeling of "isolation, persecution, and outright hatred." The introduction of equipment designed specifically for female officers would likely reduce these feelings of gender division; reducing feelings of exclusion by female officers and increasing male officers' perceptions of female officers as equals. Any active effort from law enforcement agencies towards gender inclusive representation is likely to be effective (Yu, 2018). A possible action would be the development of occupational equipment that is designed for female officers.

This study expected to find that female officers have lower perceptions than male officers of comfort, fit, and mobility in the currently available hard plates. Additionally, we expected female officers to have greater perceptions of ostracism than male officers.

## **Materials and Methods**

### ***Recruitment and Instrumentation***

A survey was distributed through email to police departments in Arkansas that have their contact information logged with the Arkansas Association of Chiefs of Police. Police officers (N=140) from 45 departments responded, with a range of 1-32 respondents within each department. See appendix 4 for distribution map. All officers had some experience with body

armour, and 96.4% stated they are required by department policy to wear ballistics vests. One-hundred and fifteen officers (82.7%) had experience with hard plates, while 15 officers were certain they did not.

The survey included demographic questions, information about the availability of equipment, scales that measure perceptions of fit, comfort, and mobility, and an instrument on ostracism in the workplace which has been modified to focus on gender (Ferris, Brown, Berry, & Lian, 2008). The instrument included 13 items which measured a unidimensional factor, workplace ostracism, which was modified to address occupational ostracism in the context of gender. Scores from the unmodified scale would have shown only ostracism which could then be compared between genders. This study is looking at gendered ostracism, that is ostracism that the respondent believes is based on their gender, and then compares the scores between genders. The gendered language was limited to woman for female officers and man for male officers within the survey. Minority stress for transgender individuals is expected to be higher in Arkansas, especially among conservative communities (Sinnard, Raines, & Budge, 2016). This study does not intend to undermine the importance of lesbian, gay, and transgender inclusion within police occupations.

### ***Description of the Sample***

The sample was comprised of 121 male and 19 female respondents. The ratio of male to female officers, 13.6% female, is higher than the distribution within the state: 9.5% female. There were more female officer respondents from higher population areas, which is representative of the expected distribution of female officers (FBI, 2017).

Respondents had evenly distributed years of service as police officers. Most female officers had been police officers for 1-5 years, or 11-15 years. No female officers responded with

more than 30 years of service. Most male officers that responded had been police officers for 21-25 years, with about 12% serving longer and about 69% serving for fewer years. Most officers that responded, both male and female, were aged between either 31 and 40 or 41 and 50. Half of the female respondents and 85% of male respondents were married. This demographic characteristic was the only one found by a chi-square analysis to have significant associations with gender. Due to the small sample size, the category of marital status was recoded into either married or not married. The chi-square test resulted in cells with counts less than five. Therefore, the Fisher's exact test was conducted. There was a statistically significant association between gender and marital status,  $p = .004$ . Cohabitation was reported six times more frequently for female officers than male officers. Male and female officers reported similar education backgrounds, with most respondents at least attending college, and about one third receiving a bachelor's degree. Most respondents were white. Both male and female officers indicated white ethnicity with more than 80% frequency. The respondents had a dispersed distribution of their current positions, but about one fifth of both male and female respondents served as patrol officers. The same number of female officers that served as patrol officers indicated they served as corporals, at a frequency three times that of male officers serving as corporals. One fifth of male respondents were chiefs of police, while there were no female chiefs of police that responded.

### ***Data Analysis***

#### *Comfort, Fit, Mobility, and Gender*

All respondents indicated they had some experience with soft body armour. Soft body armour refers to flexible vests or insertable bulletproof padding. The respondents that indicated experience with soft armour, but not hard armour will be referred to as soft armour only



respondents. Soft armour perceptions are presented in Table 1. The responses are divided into 2 groups: soft armour only respondents and those with hard armour experience. Generally, perceptions and experiences were similar with the exception of influence on wearing body armour. Soft armour only respondents more frequently indicated comfort, fit, and mobility as extremely important compared to respondents with hard armour experience.

Table 1. Soft armour perceptions

	Soft armour only respondents %	Hard armour respondents %
Type of soft armour worn		
Male-specific	66.7	64
Female-specific	6.7	6.3
Gender-neutral	20	21.6
Frequency of wear for soft armour		
Always when in uniform and on duty	86.7	89.1
Only when necessary	13.3	10.9
Influence on wearing soft armour identified as 'extremely important'		
Department policy	60	62
Comfort	60	50.5
Fit	60	54.6
Mobility	60	58.3
Overall fit satisfaction with soft armour		
Extremely dissatisfied	6.7	2
Somewhat dissatisfied	6.7	15.7
Neither satisfied nor dissatisfied	33.3	20.6
Somewhat satisfied	40	45.1
Extremely satisfied	13.3	16.7

Table 2 summarizes the types of hard armour worn by the respondents that indicated experience with hard armour. Most respondents said they were given a choice of gender-specific soft armour, but not gender-specific hard armour. This was expected, and respondents that indicated experience with hard armour were compared based on gender, with 101 males and 13 females. The comparison was focused on their differences in perceptions of comfort, fit, mobility, and gender ostracism.

Table 2. Hard armour types

	Front plate %	Side plates %	Back plate %
Do not wear	1	68.1	6.9
Shape			
Curved	67.6	8.5	45.1
Flat	30.5	8.5	47.1
Neither		13.8	
Material			
Steel	36.5	11.4	36.2
Ceramic	37.5	4.4	39.4
Polyaramid	9.6	3.5	8.5
Plastic	1.9		2.1
Protection level			
IIIA	15.4	18.5	16.1
III	26	25.9	25.8
IV	35.6	22.2	35.5
Coverage			
Small (less than 9.5 x 12.5 in)	17.5	7.7	20
Medium (9.5 x 12.5 in)	49.5	3.5	50.5
Large (greater than 9.5 x 12.5 in)	11.7	19.2	9.5

Perceptions of comfort were evaluated across seven issues. These were abrasion, rash, numbing or tingling, pinching, riding up or shifting, heaviness, and heat. Perceptions of fit were evaluated across five issues. These were tightness, gaps at the armhole, front panel placement, back panel placement, and side panel placement. Perceptions of mobility were evaluated across four issues. There were difficulty getting into squad car, restricted shooting stance, balance, and slowed movement. The issues were based on those identified in previous studies from the Justice Information Technology Center (Coppola, 2014). Table 3 shows a summary of respondents' perceptions of these issues. The results from independent-samples t-tests are shown. The two groups in the t-test are male and female, and their perceptions of the comfort, fit, or mobility issue are compared issue by issue. Exploration of the data showed a violation of homogeneity in variances in some instances, for which the Welch test was used. Only the issues where the mean

difference was statistically significant ( $p < .05$ ) are detailed in Table 3. Effect size is included as Cohen's  $d$ .

Table 3. Hard armour issues

Issue	Equal variances assumed, based on Levene p value	Group reporting issue more frequently	Mean difference	95% CI		Cohen's $d$
Comfort: Shifting plate	Yes	Males	0.785	0.035	1.606	.06
Fit: Front plate position	Yes	Males	0.870	0.129	1.611	.07
Fit: Back plate position	Yes	Males	0.954	0.231	1.677	.08
Fit: Gaps	No	Males	1.821	0.573	3.069	N/A
Fit: Chest tightness	No	Males	1.221	0.212	2.230	N/A

Perceptions of occupational equipment, such as the potential benefits of form-fitting plates, were also similar between male and female officers. Most officers agreed that form-fitting hard plates would be a positive change in terms of their equipment. Female officers were more likely than male officers to disagree that police equipment was designed for them, with a mean difference of 1.5, 95% CI [0.5, 2.5],  $t(102) = 2.99$ ,  $p = .004$ , Cohen's  $d = 0.1$ .

### *Ostracism*

The ostracism scale was modified to focus on gender for this study. Scale analysis yielded a Cronbach's alpha of .929 for females and .767 for males, which is greater than 0.7 in

both reliability analyses, indicating construct validity (Cronbach, 1951). A Welch t-test was run to determine if there were differences in gender ostracism scores between males and females due to the assumption of homogeneity of variances being violated, as assessed by Levene's test for equality of variances ( $p = 0.000018$ ). There were no outliers in the data, as assessed by inspection of a boxplot, and gender ostracism scores for each level of gender were normally distributed, as assessed by Shapiro-Wilk's test ( $p > .05$ ). Female officers had higher scores ( $M=1.94$ ,  $SD=.87$ ) than male officers ( $M=1.52$ ,  $SD=1.52$ ), a difference of 0.41; however, the difference was not found to be statistically significant ( $p=.172$ ).

### **Discussion**

Both male and female officers reported problems with comfort, fit, and mobility. Unexpectedly, male and female officers reported similar frequency of issues, with male officers reporting issues with fit more frequently than female officers. This shows that the population surveyed report dissimilar experiences to police across the United States (Grant et al., 2012).

Female officers had higher gender ostracism scores, which was also expected based on research by Harper (2016). The average score for females was lower than expected, and the difference was not statistically significant. This may be attributed to female officers having an expectation and acceptance of ostracism (Seklecki & Paynich, 2007). Alternatively, female officers may be experiencing less gender ostracism than research has shown. Previous studies on this topic have been interview or focus group style, whereas this study was an electronic survey. The effect of the setting in which the study was conducted may have had an influence on responses.

Although female officers in this population did not have a statistically significant mean difference in their ostracism scores compared to males, they did establish that they did not

believe police equipment is designed for them. It is possible that female officers' feelings of gender ostracism are influenced by the hard armour available to them. The connection between issues of comfort, fit, mobility, and gender inclusion should be explored in further studies.

### ***Limitations***

The direct influence of male-specific hard armour on female officers' feelings of inclusion cannot be identified through survey alone. Future studies should include intervention in the form of wearer trials and mixed-method research design. Future studies should also include a larger sample size, with attention to the population the law enforcement agencies serve. Another limitation of this study is that officers were evaluated only by gender, and other variables may influence perceptions of equipment including but not limited to weight, age, past experiences, and medical conditions.

Future studies should include questions about body type and measurements, as the responses to comfort, fit, and mobility may correlate with the weight, height, and build of the respondent. The region in which the study takes place might generate different results, as well. A rapport with the respondents, such as distribution through a familiar channel, could potentially increase response rates. The sensitivity of the region of the study to gender and police may be important. The social and political status of the region could influence the response rate as well as the responses.

The importance of body armour as safety equipment is conflicted with the potential inhibition of the officers using both soft and hard body armour. Both male and female officers indicate discomfort, poor fit, and reduced mobility. The results of this study were unexpected in that this sample did not indicate gender ostracism to be a prevalent issue. However, it is critical to consider that even in a sample where gender ostracism is not experienced more frequently by

female officers, the officers express agreement that police equipment is not designed for their bodies.

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#### **IV. Chapter 2: Evaluation of design criteria and development of a prototype hard plate for female police officers based on 3D modelling: A case study**

##### **Abstract**

A subject was selected for a study to identify and address important points of evaluation for the development of a methodology for designing female form-fitting plates. The dimensions of evaluation were coverage, fit, comfort, mobility, and gender inclusion. The subject was 3D scanned and prototype front and back plates were modelled based on her scan. The design criteria were drawn from responses to an initial survey and the plates were 3D printed. The subject was introduced to the prototype plates and her perceptions were compared to her initial perceptions of her currently available plates and the novel concept of form-fitting plates. Findings were that the subject preferred the prototype plates to currently available plates overall. The prototype plates were not found to improve mobility, but range of motion was found to be an important component of the methodology.

##### **Introduction**

Hard plate body armour protects police officers from bullets fired from guns as powerful as rifles (NIJ, 2008). The protection provided by hard plates is more beneficial than the cost of discomfort potentially caused by wearing the plates. Despite this, officers indicate a reluctance to wear hard armour due to discomfort (Grant et al., 2012). Discomfort and restricted mobility may be associated with gender. Female anatomy is less compatible than male anatomy with the flat plates available in the United States. Feelings of exclusion may also be associated with a lack of plates designed for female bodies (Harper, 2016). A methodology for the development and evaluation of plates for females would be beneficial to current officers, and has the potential to increase representation of population distributions in law enforcement (Yu, 2018).

Female chest plates need to compensate for the curves of the body without compromising the structural integrity of the plate. 3D body scanning allows for the development of a hard plate



prototypes directly from the surface data of the human body. Most research on body scanning specific to female anthropometry has focused on bra sizing, breast cancer, and breast augmentation (Chen, Chittajallu, Passalis, & Kakadiaris, 2010; Kim, Lee, & Kim, 2008; Niemczyk, Arnold, & Wang, 2017; Zheng, Yu, & Fan, 2007). No studies were found on occupational equipment ergonomically designed for the female body using 3D body scanning. 3D body scanning allows for the development of a hard plate prototype based directly on the human body. Female chest plates need to compensate for the curves of the female body without compromising the structural integrity of the plate. There is an optimal curvature for ballistic plates that does not detrimentally affect ballistic impact but increases ballistic limit (Stargel, 2005). Therefore, a plate with a reasonable curvature will at least be as effective as a flat plate. The design criteria for the hard plate in this study includes reasonable curvature to fit the female form, which will be determined by 3D body scan data. Additional design criteria from previous work in this research project and mobility evaluation are included in the development of the prototype.

The first purpose of this study was to initialize and evaluate the development of a front and back prototype plate for female officers using 3D technology through case study. This was achieved through the following objectives:

- To explore design criteria for form-fitting hard plates for a female officer.
- To create a 3D model of a prototype form-fitting plate based on parametrically averaged 3D body scan.

The second purpose of this study was to evaluate a method of developing a front and back prototype plate for a female officer based on design criteria from previous studies, including body scan data. The plates were developed through 3D modelling, then 3D printed and

prepared for testing. The prototype plates are compared to a lightweight dummy version of the currently available flat plates to identify accomplishments in improved ergonomic design and criteria that remain to be addressed. Key points of comparison are the coverage of the plates, range of motion, and the female officer's perceptions of coverage, fit, comfort, mobility, and inclusion.

### **Literature Review**

Body scanning is a strategy for quantifying the human body into a manipulable and statically measurable point cloud or mesh. A point cloud is a collection of points measured in space by a scanner on the X, Y, and Z plane. Specifically, the edge of a fingertip will occupy a specific spot on the X axis (horizontally), Y axis (vertically), and the Z axis (forward or backward). The location of that fingertip will be recorded as a point in a point cloud. A 3D mesh consists of thousands of triangles that are connected by points measured in space. A very detailed point cloud will create a more accurate 3D mesh.

3D body scans have become increasingly detailed and provide accurate and precise measurements quickly. Traditional apparel production is based on pattern development using body measurements taken with measuring tape. 3D body scanning allows for the surface of the human body to be measured at several locations instantaneously. Landmarks placed on the body for scanning or software identified landmarks at the bust or chest, waist, and hip can reduce measurement error and measurement time with body scanning versus physical tape measurement (Chan, Fan, & Yu, 2005; Olds & Honey, 2007; Lu & Wang, 2008).

### ***Product Development***

The fit of 3D body scan data pattern development was found by Petrova and Ashdown (2008) as well as Daanen and Hong (2008) to produce a more anatomically accurate and comfortable fit than traditional pattern development. Petrova and Ashdown (2008) found that

ease and grading in pants can be evaluated using 3D body scan measurements but did not establish a relationship between body shape and wearing ease. Daanen and Hong (2008) created skirts using 3D body scan data and found that creating a pattern based directly on the 3D body scan mesh fit better than patterns generated from the measurements taken in 3D. 3D body scan mesh data is therefore a better tool for enhancing fit than 3D body scan measurement data.

Su, Liu, and Xu (2015) showed how 3D body scans can be used to create a prototype pattern block for young females. 3D body scanning has proven to be a viable tool for creating generalized apparel sizing that fits more effectively than previously established apparel standards. Hsiao, Bradtmiller, and Whitestone (2003) used 3D body scanning to evaluate the effectiveness of harnesses. Stavrokos and Ahmed-Kristensen (2016) introduced 3D application to the design of external ear products. The usefulness of 3D body scanning will likely translate into all wearable materials and objects including ballistic vests and hard plates.

### ***Scanning Frameworks***

3D body scanning is effective on both the surface of a body or mannequin with and without apparel. Apparel can be worn by subjects in 3D scans to observe garment bagging, shown by Chan, Wong, Dong, Hu, and Chung (2006). Cui, Fan, and Wu (2016) were able to observe the air gap between garment and body when a subject is in motion using 3D scanning. Researchers will scan a subject wearing garments described as Scanwear. Scanwear is tight fitting and mimics the surface of the body without apparel but allows modesty for subjects. Common Scanwear apparel items include tank tops, leggings, fitted boxers, and full-body suits. All Scanwear is made with knitted performance fabric that fits as tightly to the body as possible. The anthropometric measurements of a 3D scan are most accurate on a nude human body, but Scanwear allows for measurements that are accurate as well. A subject may be scanned in Scanwear and subsequently scanned with apparel. These two scans may then be superimposed to

evaluate ease, fit, and bagging based on the distance between the body and the garment.

A cross-section is a two-dimensional image taken from a 3D object. Cross-sections are ideal for measuring the distance between the body scan and apparel scan at a given location, such as at the hip, waist, or bust. A cross-section such as this, which horizontally divides the body, runs parallel to the X axis and is known as a transverse cross-section. A cross-section parallel to the Y axis and vertically crossing the body front to back is known as a coronal cross-section, while a cross-section that vertically divides the body from left to right is known as a sagittal cross-section.

### ***Female Anthropometry***

Male and female bodies are anthropometrically different throughout most of the body, but especially at the critical landmarks hip, waist, and chest or bust (Krishan, 2007). Females have breast tissue at their bust that differs from male pectoral tissue in fat content, nerve endings, and glandular tissue (Jesinger, 2014). After puberty, female breasts are most often larger and more sensitive to pressure and pain than male breasts. Female breasts are less effectively represented in 3D body scanning. Lee, Kim, and Hong (2004) developed a method to compensate for the issues presented by breast tissue in 3D body scans. Generally, breast tissue will compress when garments are worn, and the physical properties of this soft tissue change is not recorded in 3D scans. However, the inclusion of a regular wear bra and representatively compressive scanwear will compensate for the attributes of breasts which cannot be scanned. Most research on body scanning specific to female breasts has focused on bra sizing, breast cancer, and breast augmentation (Chen, Chittajallu, Passalis, & Kakadiaris, 2010; Kim, Lee, & Kim, 2008; Niemczyk, Arnold, & Wang, 2017; Zheng, Yu, & Fan, 2007). No studies were found on occupational equipment designed for the female body using 3D body scanning. This research addresses this topic specifically for female police officers.

## **Methodology**

This research was conducted as a case study for a single subject. A case study is ideal because of the phenomenon under study (Baxter & Jack, 2008). The novelty of female hard plates has several undetermined implications. The perceptions of female officers in the context of body armour shape is a research topic that has not been adequately covered for the development of theory or practice. The results of this study would serve as a basis for protocol or theory development. The recruitment of the subject was partially convenient due to proximity to the research campus but also based on characteristics suggested for case study by Thomas (2011).

As part of a larger research project, an initial survey was sent to police officers through the study site's Association of Police Chiefs. Female participants at the end of that survey were invited to participate in this study and a single subject was selected. The subject chosen indicated perceptions of coverage, fit, comfort, mobility, and inclusion that were closely aligned with the typical female responses from the initial survey.

## ***Survey***

The initial survey provided a foundation for design criteria. A post-survey was created to evaluate the subject's perceptions of the prototype. Both surveys were taken electronically. The items included for comparison were perceptions of coverage, fit, comfort, mobility, and inclusion. The subject was also asked to rank her satisfaction of fit in the neck, chest, waist, armhole, shoulder, and overall.

## ***Laboratory Procedures***

The female police officer came to the research campus of a large public university in a mid-South US state to participate in this study. She was provided a consent form, scanned on the laboratory body scanner, and evaluated for mobility. The mobility evaluation was based on normal range of motion and locations of evaluation specified by Gibson et. al (2018). The

subject was given a \$25 gift card incentive upon completion of procedures.

The subject was scanned in Scanwear using a Human Solutions VITUS XXL body scanner. The Scanwear in this study was a tight tank top over the brassiere she would normally wear to work and tight leggings. She was scanned at least once, with subsequent scans being compared for quality and the scan with the highest register scan was used in the final development.

The subject was evaluated for range of motion using a goniometer with and without a carrier vest containing medium size dummy hard plate inserts. The subject expressed that the dummy plates were shaped much worse than the plates she had experience with and about the same weight. It is important to clarify that the subject most often wore smaller, rectangular plates for ease of movement and did not often wear plates with the coverage of the plate size that was being investigated in this study. Mobility was evaluated at the neck, shoulder, hip, and thoracic lumbar spine. The subject indicated the point in each movement that she felt resistance from the plate insert, and then completed the movement. This procedure was repeated for evaluation of the prototype plate.

### ***3D Modelling***

The 3D body scan of the subject was converted into a workable format that could be used in the software Blender. The 3D file was cleaned and registered to a workable mesh. The prototype was a mesh made entirely based on the surface data of the scan with a focus on the design criteria determined from previous research.

### ***Design Criteria***

Responses to the initial survey were included in the design criteria of the prototype plate (West, 2019). Responses associated with design criteria from the initial survey include compensation for breasts, contoured fit to reduce plate shifting, and less bulk. Mobility

restrictions that could be improved through plate design include a slenderer profile that does not restrict cross-body reaching. An unpublished study from the National Institute of Justice also found that women may want to avoid appearing feminine, and some responses indicated a population of females within law enforcement that wish to be “one of the boys”. The design criteria are summarized below:

- Compensation and contouring for female form
- Reduced extraneous plate surface and increased coverage of vital areas
- Masculine, angular, militaristic design appearance

### *Prototype Development*

The prepared scan was imported to Blender. A mesh plane was made to cover the same area as the dummy plate from mobility testing. The mesh face was extruded to a non-specific thickness that was large enough to capture the curve data from the body scan mesh. The plate extrusion was superimposed onto the body scan mesh with the top of the plate mesh even to the top of the scan mesh sternum, as per ASTM recommendations for plate placement (2015). The curve data was extracted using a Boolean modifier. The extracted mesh was placed into a template and rotated to ensure the coverage area was not artificially increased due to natural body curvature. The mesh was simplified into triangles to achieve a masculine, militaristic design. The mesh was cleaned and prepared in a 3D printing software to insure there were no flaws in the model. A plate was made for the front and back, which were inserted into the same carrier that held to dummy plate. The 3D printer used to print the prototype was a Raise3D large printer with PLA filament.

### **Analysis and Discussion**

The subject for this case study reported service years as a police officer within the same subgroup as 15% of the officers in the sample. She reported serving as a patrol officer, detective,

supervisory officer, and field training officer prior to her current position of sergeant. The hard plates the subject had experience with were gender neutral, flat front and back plates made of polyaramid material, type III protection, and 9.5 by 12.5 inches coverage. She reported that she most often wears her body armour system over her uniform with a sports bra for comfort. She identified department policy, comfort, fit, and mobility each as extremely important in terms of hard armour.

The subject's initial reaction to the plates was positive. She approved of the appearance and was surprised by the feeling of wearing the plates. Another thought she expressed was that she had not thought about female plates prior to participation in this study. She seemed to have an overall positive impression of the plate. Screenshots of the 3D model of the plate are shown in figures 1 and 2.



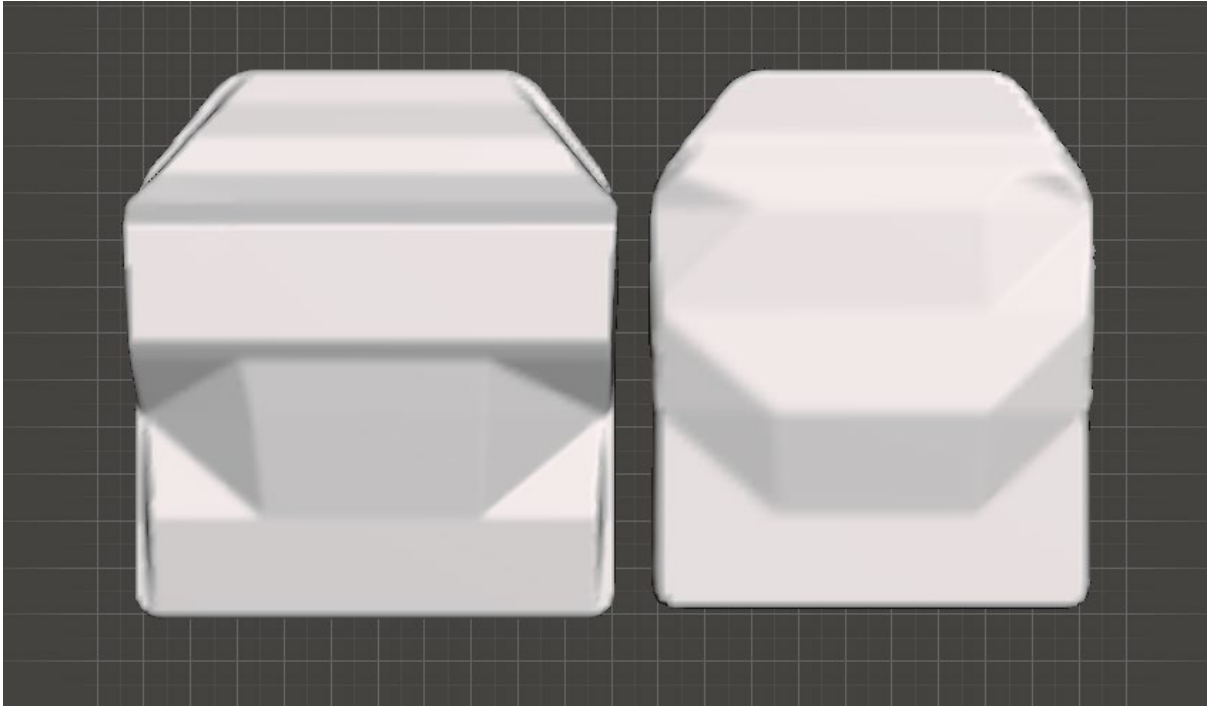


Figure 1. Left, front plate strike face. Right, back plate strike face.

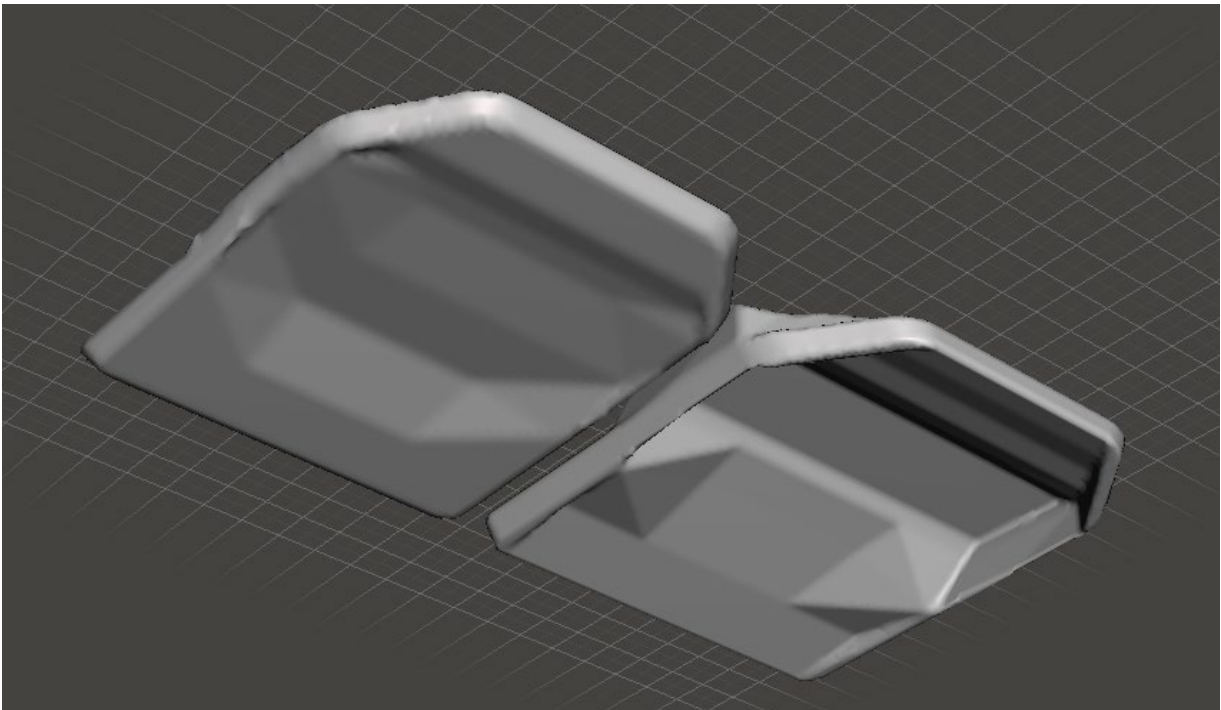


Figure 2. Left, back plate body face. Right, front plate body face.

### ***Range of Motion***

Table 1 details the range of motion measurements taken with a Lafayette Gollehon goniometer. Each numeric entry is in degrees. The carrier column shows the subject's range of motion while wearing only the plate carrier. The dummy column shows the subject's range of motion while wearing the plate carrier and the dummy plates in front and back. If the subject experienced resistance, the location of resistance was recorded. The prototype column, which shows the subject's range of motion while wearing the plate carrier and the prototype plates for front and back, has a resistance column to its left as well.

<b>Movement</b>	<b>Carrier</b>	<b>Resistance</b>	<b>Dummy</b>	<b>Resistance</b>	<b>Prototype</b>
	(degrees)	(degrees)	(degrees)	(degrees)	(degrees)
<b>Shoulder</b>					
<b>Extension</b>	61		62		61
<b>Flexion</b>	130		130		135
<b>Abduction</b>	80		80		80
<b>Vertical adduction</b>	25	15	25		28
<b>Horizontal adduction</b>	45	40	45		50
<b>Hip</b>					
<b>Flexion, straight knee</b>	72		72		75
<b>Flexion, bent knee</b>	109		108		115
<b>Spine</b>					
<b>Flexion</b>	96		85	31	95
<b>Extension</b>	38		34		32
<b>Lateral flexion</b>	35	24	40		30
<b>Rotation</b>	75	55	75		80

Table 1. Range of motion of subject in 3 conditions

The subject experienced resistance wearing the dummy plates during the vertical shoulder adduction, horizontal shoulder adduction, spine lateral flexion, and spine rotation movements. The shoulder adductions are both movements across the midsagittal plane, which would be inhibited by something worn on the chest. Similarly, the spine movements would require the flexibility of the chest. Each instance of resistance for the dummy plate was not experienced by the subject in the prototype plate. The subject did feel resistance in the spine

flexion, which was not a movement that caused resistance with the dummy plate. Across all movements, range of motion increased by an average of 1.92 degrees for the subject while wearing the prototype plate. The movements with the highest improvement of range of motion are shoulder flexion, horizontal shoulder adduction, hip flexion with a bent knee, spine flexion, and spine rotation. The only movement with notable reduction of range of motion was the lateral flexion.

### ***Coverage***

The subject expressed that she was “moderately satisfied” with the coverage of her currently available plates. She also felt that her body “probably [did] not” compromise the coverage of the plates. She also did not identify any female features of her body that she felt compromised coverage. When asked about the prototype plates, she expressed that she was “extremely satisfied” with the coverage. She also felt that the prototype plates compensated “a lot” for feminine features at the neck, collarbone, bust, and ribcage. She felt that the prototype plates moderately compensated for her shoulders, waist, torso length, stomach, and back curvature. Her hips also seemed “a little” compensated for by the prototype plate design.

### ***Fit, Comfort, Mobility Perceptions***

The subject identified few issues of fit with the plates she currently uses. She did experience front and back panel position problems more often than other issues. The fit of the prototype plate was about the same as the plates she currently uses for the issues of gaps at the arm and back panel position. The front panel position was “somewhat better”. She felt that the tightness around her bust was “much better” than the experience she has had with flat plates. She specified that the prototype “better conformed to [her] chest” and that “it also felt slightly easier to breathe [and] expand [her] chest”. Although she expressed neither satisfaction or dissatisfaction with her currently available plates, she was extremely satisfied with the prototype

plate fit overall and at her neck and chest.

The comfort issues she experiences with her currently available plates are mostly related to temperature and plates shifting or riding up. The prototype plate made each of these issues “much better”, and abrasion and pinching seemed “somewhat better” as well. Issues of rash and numbing were about the same for the subject. She also expressed that the prototype plates were “more spacious in the chest area” and that there was “not as much pressure on the breasts”.

Mobility issues were all about the same. The issues that were unimproved were difficulty sitting, restricted shooting stance, and reduced balance.

### ***Gender Inclusivity***

Perceptions of gender inclusion were evaluated through the subject’s agreement with statements. The subject neither agreed or disagreed that form-fitting plates would have a positive impact on her performance, that they would be more comfortable or easier to move in, or that police equipment was designed for her prior to being introduced to the prototype plates. After trying on the prototype plates, she still neither agreed or disagreed that the availability of form-fitting hard plates would make her feel respected by her co-workers and superiors, empower her to pursue career challenges, increase her feelings of belonging, or reduce her inhibitions as a female police officer.

After trying on the prototype plates, her opinion on form-fitting plates changed the agreement that they would have a positive impact on her performance, that they would be more comfortable, and that movement would be easier. She strongly agreed that these prototype plates were designed for her.

### **Conclusion and Future Research**

This study presents a foundation for the development of female hard plate body armour. Important areas of evaluation were identified as coverage, fit, comfort, mobility, and inclusion.

Each category should be explored with individual attention but with interconnected intention. The perceptions of the population were found to be important indicators of design features as well.

Coverage is imperative for the effectiveness of hard plates. Increased coverage that does not reduce fit, comfort, or mobility is ideal. In this study, the subject was more satisfied with the coverage of the prototype plate than her currently available plates. Compensating for body features naturally increased the coverage of the plate, as the extraction of the body scan covered the same area as the dummy plate.

Fit was measured in satisfaction as well as general fit, unlike comfort and mobility. This could be a dimension that is evaluated for all areas. Generally, the subject was much more satisfied with the fit of the plate, and multiple issues were improved. Comfort was improved about as much as fit. The mobility was evaluated more concretely with range of motion. This would be an important measure of how well a female hard plate improves mobility. Range of motion should be evaluated more actively with the subject performing more movements that are associated with the occupation. For example, an evaluation of the subject's ability to get in and out of a squad car would be better. In this study, the prototype did not improve mobility very much.

The gender inclusivity of form-fitting plates was the most challenging facet to evaluate in this study. A qualitative study would be the recommended follow-up for the importance of gender inclusivity in occupational equipment. The subject in this study did not have expressed feelings of exclusion based on her gender, and especially not in terms of the equipment available to her. However, her perceptions of the possible benefits of form-fitting plates changed through her participation in this case study.

The novelty of the design would require further testing in prototype production. The ballistics of plates at the areas that have slopes that angle more towards the wearer than a flat plate would need investigation to insure the safety of the officers wearing the plate. A suggested procedure would be the use of Finite Element Analysis on the 3D mesh with the physics of a material such as steel or ceramic. The ballistic standard testing through the National Institute of Justice would need to include new ballistic testing for the sloping areas should a prototype with the characteristics of this prototype become an available product.

The currently available hard armour is not designed for female police officers. This study presented a case in which a female police officers that did not have expressed problems with her currently available armour found that form-fitting plates may be preferable for her. The important points of evaluation in this study which should be expanded on are improvements by a form-fitting plate in the context of coverage, fit, comfort, mobility, and inclusivity. Each was found to be important to the subject and with the potential to be addressed by a form-fitting plate designed based on the anatomy of female police officers.

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## V. Conclusion

This research project was a two-part study on Arkansas police officers. Each study covered the dimensions of fit, comfort, mobility, and gender inclusion. The focus of this research project was on hard armor plates, which are flat and designed for male anthropometry.

The first study was prepared for submission to *Police Practice and Research*. The scope of the target journal included key elements of the study. The bridge between academic research and the occupation of policework was strengthened by the completion of this study. The results should give officers in the study population some new perspective on their workplace and fellow officers. The study showed that the participants in the study population were generally not experiencing feelings of gender ostracism. The male officers also reported fit issues more frequently than female officers with a statistically significant difference. Despite these conditions, statistically significantly more female officers in the population disagreed that police equipment is designed for them. This finding presented a new consideration for female officers. Female officers may feel that their equipment is not made for them without the context of their gender. The female officers varied on their opinions of fit, comfort, mobility, coverage, and inclusion. A single subject whose perceptions were aligned with the central tendency of responses was chosen for the second study in the research project.

The case study that followed the first study focused on this single subject. The study was prepared for submission to *International Journal of Fashion Design, Technology, and Education*. The scope of the journal includes the development of new methods in the subject area of anthropometry and product development. For this study, the subject was 3D scanned and evaluated for mobility based on range of motion in a plate carrier holding dummy plates. Form-fitting prototype plates were developed based on her 3D scan and design criteria from responses

in the first study. The prototype plates were 3D printed and inserted into the plate carrier. The subject repeated the range of motion movements and then completed a survey on the prototype. The subject expressed that the prototype was considerably better than flat plates, especially at the bust. However, the prototype was not found to improve mobility very much. The important findings from the case study summated to be a methodology for the development and evaluation of prototype plates. The dimensions of fit, comfort, and mobility were easily evaluated and expressed as important by the subject. Coverage was a dimension that should be a standard point of evaluation due to its safety importance. The relationship of fit, comfort, mobility and coverage were established to be interconnected in this study, with each contributing to and influencing the perceptions of each other. The evaluation of inclusion is recommended for a more qualitative study due to the complexity of the phenomenon and potential variation from subject to subject and between populations.

Limitations of this research project were mainly in the sample. The sample size was not large enough to generalize to the population of all Arkansas police officers. The distribution channel also limited the number of respondents. The response rate was not ideal. A shorter survey may have been advantageous. Another issue was the proximity of some participants to the research campus. The 3D prototype would have been generalizable with more subjects' 3D scans. A prototype based on several bodies would accommodate a wider range of body types and bust sizes.

Future studies should include the analysis of the interconnectedness of fit, comfort, mobility, and coverage perceptions of hard armor plates. A larger sample population from a wider distribution would give more generalizable results. It is important to consider in future studies the variation of policy across state lines in the United States and between departments within

states. Additionally, consideration of the regional status, such as social and political perceptions of police officers and gender, would be beneficial to understand response rate and responses. Consideration of the region would be important in the development of the survey. For example, this study uses woman and man because of the conservatism of the region. This may not be appropriate in a more liberal region.

The use of 3D body scanning would be beneficial for a larger sample with the use of parametric averaging. Continued development of the prototype should include Finite Element Analysis to evaluate the risk of ballistic ricochet. A case study on subjects with outlying perceptions would be a recommended qualitative analysis. Female officers were found in this study that objected to the idea of gender exclusion, and others were found to experience it in extremes. These polar experiences would be important to analyze and compare the dimensions of fit, comfort, mobility, and coverage perceptions across varying contexts of inclusivity perceptions.

The hypotheses of this research project were not supported in the study. The project effectively introduced a methodology to develop and evaluate form fitting prototype plates based on 3D body scans. The focus on fit, comfort, and mobility was found to be beneficial with the added dimension of coverage. These perceptions were established as interrelated. The impact of form-fitting plates on gender inclusivity was not established in this study. However, a key finding was that female officers may have never considered form-fitting plates, and the introduction of the concept may influence them to consider the potential costs of the currently available plates and the potential benefits of plates designed for their female anthropometry.

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## VII. Appendices

### Appendix 1. IRB approval letter.




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**To:** Sarah West West  
 BELL 4188  
**From:** Douglas James Adams, Chair  
 IRB Committee  
**Date:** 12/17/2018  
**Action:** **Expedited Approval**  
**Action Date:** 12/17/2018  
**Protocol #:** 1811157344  
**Study Title:** DESIGNING A HUMAN-CENTRIC RIGID BODY ARMOR FOR FEMALE POLICE OFFICERS: THE IMPLICATIONS OF FIT ON PERFORMANCE AND GENDER INCLUSIVITY  
**Expiration Date:** 12/04/2019  
**Last Approval Date:**

The above-referenced protocol has been approved following expedited review by the IRB Committee that oversees research with human subjects.

If the research involves collaboration with another institution then the research cannot commence until the Committee receives written notification of approval from the collaborating institution's IRB.

It is the Principal Investigator's responsibility to obtain review and continued approval before the expiration date.

Protocols are approved for a maximum period of one year. You may not continue any research activity beyond the expiration date without Committee approval. Please submit continuation requests early enough to allow sufficient time for review. Failure to receive approval for continuation before the expiration date will result in the automatic suspension of the approval of this protocol. Information collected following suspension is unapproved research and cannot be reported or published as research data. If you do not wish continued approval, please notify the Committee of the study closure.

Adverse Events: Any serious or unexpected adverse event must be reported to the IRB Committee within 48 hours. All other adverse events should be reported within 10 working days.

Amendments: If you wish to change any aspect of this study, such as the procedures, the consent forms, study personnel, or number of participants, please submit an amendment to the IRB. All changes must be approved by the IRB Committee before they can be initiated.

You must maintain a research file for at least 3 years after completion of the study. This file should include all correspondence with the IRB Committee, original signed consent forms, and study data.

cc: Betsy Garrison, Key Personnel

## Appendix 2. Participation consent form for first survey.

### ATTITUDES AND BELIEFS ABOUT BODY ARMOR SYSTEMS

#### Consent to Participate in a Research Study

Principal Researcher: Sarah West

Faculty Advisor: Dr. Betsy Garrison

#### INVITATION TO PARTICIPATE

You are invited to participate in a research study about body armor for police officers. You are being asked to participate in this study because you are an active duty police officer.

(1) Principal Researcher: Sarah West, sbwest@uark.edu, 479-530-5521

Faculty Advisor: Dr. Betsy Garrison, megarris@uark.edu, 479-575-4305

(2) If you have questions or concerns about your rights as a research participant, please contact Ro Windwalker, the University's Human Subjects Compliance Coordinator, at 479-575-2208 or irb@uark.edu.

(3) The purpose of this survey research is to investigate the fit of hard plate body armor for men and women and its influence on performance and feelings of gender inclusion.

(4) You are being asked to complete a 30-minute questionnaire because you are an active duty police officer.

If you are a female, you will also be invited to participate in a second part of this study at the end of this survey. Should you opt out, your responses will be kept confidential to the extent allowed by law and University policy.

Should you choose to participate in the second part, your responses will be recorded with the contact information you provide.

(5) Participation is voluntary and refusing to participate will not adversely affect any other relationship with the University, its researchers, or you professionally. There are no expected risks or benefits to participating in the survey.

### Appendix 3. Participation consent form for body scanning and prototype survey.

#### DESIGNING A HUMAN-CENTRIC RIGID BODY ARMOR FOR FEMALE POLICE OFFICERS: THE IMPLICATIONS OF FIT ON PERFORMANCE AND GENDER INCLUSIVITY

##### Consent to Participate in a Research Study

Principal Researcher: Sarah West  
Faculty Advisor: Dr. Betsy Garrison

##### INVITATION TO PARTICIPATE

You are invited to participate in a research study about body armor for female police officers. You are being asked to participate in this study because you are a female, active duty police officer.

##### WHAT YOU SHOULD KNOW ABOUT THE RESEARCH STUDY

###### *Who is the Principal Researcher?*

Sarah West, sbwest@uark.edu, 479-530-5521

###### *Who is the Faculty Advisor?*

Dr. Betsy Garrison, megarris@uark.edu, 479-575-4305

###### *What is the purpose of this research study?*

The purpose of this study is to examine the fit of hard plate body armor for women and its influence on performance and feelings of gender inclusion.

###### *Who will participate in this study?*

Female police officers in Arkansas.

###### *What am I being asked to do?*

Your participation in will require the following:

You will be asked to come to the University of Arkansas Home Economics building. Then, you will be asked to perform simple movements while wearing body armor and undergo body scanning. Body scanning will be like going through a security scanner at the airport. It is very quick and there is no discomfort or risks associated.

For the follow-up, you will be able to choose whether you would like to meet at the University of Arkansas or at your place of work. You will be asked to perform simple movements and fill out a short questionnaire.

###### *What are the possible risks or discomforts?*

There are no anticipated risks. Mobility will be evaluated with reasonable movements.

###### *What are the possible benefits of this study?*

There will be a \$25 gift card provided.

###### *How long will the study last?*

The study will include a 15-minute body scanning session and mobility evaluation. Once the prototype is developed, no more than 3 months later, you will be asked to try it on and give feedback which should take no longer than 15 minutes.

###### *Will I receive compensation for my time and inconvenience if I choose to participate in this study?*

Yes; see above.

*Will I have to pay for anything?*

No cost will be associated other than cost of travel to the laboratory.

*What are the options if I do not want to be in the study?*

If you do not want to be in this study, you may refuse to participate. Also, you may refuse to participate at any time during the study. You will not be affected in any way if you refuse to participate.

*How will my confidentiality be protected?*

All information will be kept confidential to the extent allowed by applicable State and Federal law.  
All data will be kept on a password protected computer in a secured laboratory.

*Will I know the results of the study?*

At the conclusion of the study you will have the right to request feedback about the results. You may contact the faculty advisor, Dr. Betsy Garrison, or Principal Researcher, Sarah West. You will receive a copy of this form for your files.

*What do I do if I have questions about the research study?*

You have the right to contact the Principal Researcher or Faculty Advisor as listed below for any concerns that you may have.

Sarah West, sbwest@uark.edu, 479-530-5521

Dr. Betsy Garrison, megarris@uark.edu, 479-575-4305

You may also contact the University of Arkansas Research Compliance office listed below if you have questions about your rights as a participant, or to discuss any concerns about, or problems with the research.

Ro Windwalker, CIP  
Institutional Review Board Coordinator  
Research Compliance  
University of Arkansas  
109 MLKG Building  
Fayetteville, AR 72701-1201  
479-575-2208  
[irb@uark.edu](mailto:irb@uark.edu)

I have read the above statement and have been able to ask questions and express concerns, which have been satisfactorily responded to by the investigator. I understand the purpose of the study as well as the potential benefits and risks that are involved. I understand that participation is voluntary. I understand that significant new findings developed during this research will be shared with the participant. I understand that no rights have been waived by signing the consent form. I have been given a copy of the consent form.

**Appendix 4. Distribution of respondents' police departments.** The counties are shown with their respective populations differentiated by color.

