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Assessment of body armor design on physical performance during simulated law enforcement activities

David Rashad Close

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ASSESSMENT OF BODY ARMOR DESIGN ON PHYSICAL PERFORMANCE
DURING SIMULATED LAW ENFORCEMENT ACTIVITIES

By
David Rashad Close

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Masters of Science
in Industrial Engineering
in the Department of Industrial and Systems Engineering

Mississippi State, Mississippi
December 2010
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By

David Rashad Close
ASSESSMENT OF BODY ARMOR DESIGN ON PHYSICAL PERFORMANCE
DURING SIMULATED LAW ENFORCEMENT ACTIVITIES

By

David Rashad Close

Approved:

Kari Babski - Reeves
Associate Professor of Industrial and
Systems Engineering
Mississippi State University
(Director of Thesis)

Lesley Strawderman
Assistant Professor of Industrial and
Systems Engineering
Mississippi State University
(Committee Member)

Daniel Carruth
Assistant Research Professor of the
Center of Advanced Vehicular Systems
Mississippi State University
(Committee Member)

John M. Usher
Professor and Graduate Coordinator of
Industrial and Systems Engineering
Mississippi State University

Sarah A. Rajala
Dean of the Bagley College of Engineering
Mississippi State University
The objective of this research was to evaluate the impact of current body armor design on physical performance during simulated law enforcement activities. Twenty participants completed three trials of 13 individual activities representative of routine law enforcement activities. Three body armor configurations were evaluated: baseline (i.e., no armor), concealable body armor, and external body armor. Dependent variables included task completion time, heart rate, and center of pressure (COP). Repeated measures ANOVAs were used to test the dependant variables, with Tukey’s HSD post hoc tests used where appropriate. Results showed that the vertical and horizontal components of COP were affected by armor condition, time was not affected by armor condition, and heart rate was found to have significance in the EBA condition. The findings show that there is evidence to suggest that armor can affect the physical performance of wearers as they go about completing physical activities.
DEDICATION

Thank you so much to all of the people that have made this thesis possible. I have to give a very important thank you to my advisor Dr. Kari Babski-Reeves, for you have given me opportunity and guidance throughout my graduate years. You actually made learning fun and interesting to me again. I also would like to thank Dr. Daniel Carruth, as you helped show me the expanded side of engineering. I also must thank my lab colleagues, as your laughter and friendship helped make these the happiest engineering years of my life. Thank you Arshish Tarapore, Robin Littlejohn, Shaheen Ahmed, and Kylie Nash for being who you are and making the lab a great environment. Finally, I must thank my parents Samuel and Doris Close. You have always supported and encouraged me in life and I will be forever grateful to you.
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CHAPTER I
INTRODUCTION

Ballistic impacts to the body injure, and sometimes kill, police officers every year. While ballistic properties of body armor are important, there are known compliance issues associated with officers wearing their armor. A survey was conducted in 2007 on the policies and practices regarding body armor and police officers. The survey, conducted with 782 police agencies, revealed that only 59% require that their officers wear body armor when on duty (Bureau of Justice Assistance, 2009). Even worse, out of the agencies that require body armor usage, only half of those agencies have any sort of written policy on it, making enforcement even harder (Bureau of Justice Assistance, 2009). Due to the lack of research on how body armor affects law enforcement personnel during everyday duties, more research focusing on the performance of body armor during physical tasks is needed.

There is research available that shows that body armor design has an impact on the performance of the user, though this research is limited. Results of studies on armor flexibility, rate of movement, and overall task performance (Bensel and Lockhart, 1975; Bensel, et al., 1980) indicated that flexibility was significantly reduced for subjects while wearing body armor, movement rate was affected by adding load-carrying equipment, task performance was affected by armor design (specifically the collar and shoulder design), and performance was gender-specific (Bensel, et al., 1980). The results from these research findings, while important, must be taken within context. Specifically,
while the research gives valuable insight to body armor, the armor types that were used were of military designs. The design, as well as function, of military body armor can be significantly different than that of law enforcement body armor, and therefore, these findings may not be directly applicable to the law enforcement arena.

The objective of this research was to evaluate the impact of current body armor designs on physical performance during simulated law enforcement activities. A laboratory-based study was designed to assess the effects of various armor configurations on task performance. The information gained will be used to improve future armor designs.

**Scope and Limitations of the Study**

This study used three different armor configurations (no armor, concealable, and external). Although there are various designs and configurations for concealable and external armor, only a single design for each configuration was used due to the small sample size. Other areas that could potentially affect performance while wearing body armor, such as flexibility and comfort, were not considered for this study.

The simulated activities were designed to be representative of essential activities law enforcement personnel perform while on the job. Since the activities are only representative of essential activities, it should not be assumed that these activities chosen for this study are the only activities that this user population performs. Extreme events (such as running) were not considered in this study. Since the activities in this study are simulations, there is no “true” threat to participants and so there is a possibility that participant performance may not be fully representative of actual performance in “live”
situations. However, as this study was designed to examine how body armor affects performance, simulated tasks were considered sufficient.
CHAPTER II
LITERATURE REVIEW

The current focus of body armor research has been the improvement of ballistic protection (National Institute of Justice, 2005). In November of 2003, former Attorney General John Ashcroft introduced the new Body Armor Safety Initiative from the Justice Department (National Institute of Justice, 2005). This initiative was created in response from law enforcement concern of the effectiveness of then-issued Zylon®-based body armor. Concern over the capabilities of the vest threatened law enforcement confidence in body armor protection. Significant research in the development and evaluation of body armor has been conducted since then, resulting in changes in armor design standards. This focus on ballistic protection and environmental degradation, while important, does not address compliance issues or potential issues associated with armor impacts on performance.

Current Trends in Body Armor Evaluation

The origin of the current focus on ballistic and environmental protection regarding body armor began with an injury to a police officer in 2003. In 2003, a Pennsylvania police officer, while wearing a then NIJ compliant-current body armor, sustained substantial injuries while in the line of duty (Gonzales AR, Schofield RB, Hart SV, 2005). This incident prompted a serious inquiry into then-current body armor by the U.S. Department of Justice. Results of the inquiry showed that out of 103 body armors tested, only 4 actually met the NIJ requirements at that time (Dolez, P.I. and Vu-Khanh,
Armor, made out of Zylon® material, was found to degrade in strength over time when exposed to moisture (even in the form of humidity). Another problem was that it was very difficult to discern if the body armor was in good condition (basing condition on if it could effectively stop ballistic projectiles) based on its appearance (Dolez, P.I. and Vu-Khanh, T., 2009). Due to these findings, NIJ has been concerned with the ballistic performance and environmental degradation of body armor and has passed those concerns to body armor manufacturers (National Institute of Justice, 2005). Concerns over ballistic performance degradation was the catalyst for the NIJ 2005 Interim Requirements for Bullet-Resistant Body Armor, which lays out the performance standards (with a heavy emphasis on ballistic performance) that all manufacturers must adhere to (National Institute of Justice, 2005). However, there is still no consideration provided to the ergonomic impact of body armor on task performance in the Ballistic Resistance of Personal Body Armor, NIJ Standard 0101.04 (i.e., physical performance measures) (National Institute of Standards and Testing, 2001). Due to the insistence of NIJ on increasing environmental and ballistic protection, body armor manufacturers have ignored trying to improve the ergonomic functionality of body armor designs. NIJ has, however, admitted that physical performance degradation should be taken into account and incorporated into its body armor compliance testing program eventually (National Institute of Justice, 2005).

While there have been numerous studies on the effects of body armor related to fatality and injury reduction, there are no significant studies on how armor design affects task performance available in the public domain. There has been recent research into expanding how body armor is evaluated. Horsfall et al. (2005), for example, conducted material tests to examine subjective flexibility and comfort of users wearing body armor.
Ergonomics in Other Law Enforcement Suits

Body armor is not the only type of personal protective equipment (PPE) that law enforcement officers (LEO) use. Although body armor in the U.S. currently has no ergonomic standards, another PPE worn by LEOs, the chemical/biological (CB) suits, does. CB suits are employed during situations where chemical and/or biological hazards have occurred. Ergonomic standards exists for CB suits, using the ASTM F 1154 Standard Practices for Quantitatively Evaluating the Comfort, Fit, Function, and Integrity of Chemical-Protective Suit Ensembles for the evaluation of CB suits (Edler et al, 2010). While ergonomic standards exist for the CB suits, proponents also realize that the standards are not stringent enough and are currently working on expanding the standards. Current standards are “global and general, allowing pass/fail testing only for ensemble performance and do not allow for quantitative evaluation of ensembles or evaluation through mission-based tasks” (Edler et al, 2010). Proponents of ergonomic evaluations for CB suits are currently trying to expand the standards so that they better encompass the needs and movements of LEOs when they are engaged in activities common when wearing the suits.

Summary

Over the last 4 years, manufacturers of body armor have had to comply heavily with new standards from the NIJ. The standards, however, deal mainly with the ballistic performance of body armor and do not take into consideration ergonomic performance. When it comes to any sort of PPE, it is important to make sure that the protection requirements do not degrade the ability of the wearer to perform tasks while wearing the equipment. This study will focus on the ergonomic performance of body armor during simulated law enforcement officer tasks.
CHAPTER III
METHODOLOGY

Design of Experiment

A two factor repeated measures ANOVA was used to assess the effects of body armor condition (3 levels) and trial (3 levels) on task performance measures for several task simulations. Exposure to the armor conditions and tasks were assigned randomly.

Independent Variables

Independent variables for this study were armor condition (3 levels) and trial (3 levels). Three armor conditions were investigated: no body armor (NO ARMOR), concealable body armor (CBA) (XT3A-2—no plate, threat level IIIA, American Body Armor), and external body armor (EBA) (GP-1000-IIIA (plate model SN-III, size 8x10) with shoulder protectors (threat level IIIA, Protective Products International) (Figure 1). These body armor designs were selected to cover the range of possible armor designs, though other designs could have been selected. When possible, participants wore their own body armor to minimize body armor fit effects. If the participants did not have body armor of their own, armor was provided by the researcher. Participants completed all activities for three separate trials in order to give participants familiarity with the tasks and to gather additional data further details are provided in the Task section below.
Dependent Variables

Dependent variables for this study were task completion time, heart rate, and center of pressure (COP) measurements. Heart rate and task completion time were collected and analyzed for all simulated tasks. COP was collected and analyzed only for two tasks (sitting and kneeling). COP was not collected for all tasks due to the potential for map destruction (as some of the tasks include rapid movement that the mats cannot handle and require larger areas of space to perform that the mats cannot encompass).

Measurement of Task Completion

Task completion times for each trial of each task was collected using motion capture data collected as part of a larger study. Task start was defined as the initial movement that occurs from a predefined posture. Task end was defined as the completion of the task identified by a predefined posture (e.g., placing the gun back in the holster, placing the hands on the door frame, etc.). For tasks in which there was not a defined end posture, task end was defined by analyzing the motion capture data to determine a generic end posture for the user. Time was measured in seconds.
Measurement of Heart Rate

Participant heart rate was monitored during task performance using a Polar S810 heart rate monitor (Polar, NY). The Polar S810 system consists of a wrist monitor and chest strap. The wrist monitor stored heart rate data during the performed activities. The chest strap was strapped around the participant with the logo resting near the xiphoid process on the chest. Prior to attachment, the electrodes of the chest strap were wetted with water to improve signal fidelity. A researcher placed the logo of the strap at the desired location on the participant, the participant then held the logo in place, and the researcher attached the strap behind the participant. After ensuring the heart rate signal was being received (the wrist monitor was reading a heart rate), the participants put back on their shirt.

Resting heart rate was collected following a five minute rest period where the participant sat quietly with their hands resting on their thighs. Heart rate was recorded every minute until three consecutive heart rates were collected that were with 5 bpm. The average of these values was used as the resting heart rate.

During testing, the heart rate monitor ran continuously for each task, though new files were created for each task. Since some tasks were very short (e.g., sitting and kneeling), stopping and starting the heart rate monitor at each trial resulted in participant frustration and significantly increased the testing time during preliminary testing. Therefore, it was decided that for each task the monitor would begin recording prior to the first trial and end recorded following the third trial. Although the heart rate monitor ran continuously, a marker within the software was activated in order to separate the tasks out. Due to software limitations, however, marking trial results was not done.
Following testing, data was downloaded to a PC following testing using the E600 model’s E Series software, created by Polar. Change in heart rate, percent increase in resting heart rate, and difference in percent of maximum were analyzed. Change in heart rate was defined as the change from baseline. Percent increase in resting heart rate was defined as the percentage that the heart rate reaches starting from rest to when work occurs. Difference in percent of maximum was defined as the percent difference between the working heart rate and base heart rate. Change in heart rate was calculated using equation 1, while equations 2 and 3 showed how percent increase in resting heart rate and difference in percent of maximum were calculated:

\[
\text{Testing HR} - \text{Baseline HR} = \Delta \text{HR} \quad (1)
\]

\[
\left(\frac{\text{RestingHR}}{\text{MaxHR}}\right) - \left(\frac{\text{MeanHR}}{\text{MaxHR}}\right) \times 100 = \%\text{Incr} \quad (2)
\]

\[
\left(\frac{\text{MeanHR}}{\text{BaseHR}}\right) - 1 \times 100 = \%\text{DiffMax} \quad (3)
\]

As the monitor ran continuously between task trials, data not associated with the task was eliminated.

**Measurement of Center of Pressure**

Two FSA Sensor pressure maps, developed by Verg Inc., were used to collect interface pressure measurement at the seat pan and floor during the sit/stand and kneel/rise tasks. During the sit/stand task, one pressure map was situated and attached to a seat pan of a flat chair that had the back rest removed and the other pressure map was situated directly in front of the chair on the floor. During the kneel/rise task, one pressure map was situated in a designated area on the floor for the participants to kneel and rise on. FSA 4.0 software stored the data automatically and peak pressure was extracted for each trial, consistent with other studies of interface pressure (e.g., Bubb, 2007; Reed et
al., 1994). Both horizontal and vertical pressure components, measured in inches, were extracted and analyzed separately. The center of pressure origin for the pressure maps was located in the lower left corner of the sensing area. Therefore, vertical measures that had a higher value indicated a more forward posture, and higher valued horizontal measures indicated more emphasis toward the right. The sample rating for this part of the study was set at 40 Hz.

**Tasks**

The tasks examined during the study were divided into four areas: simple movement, tactical movement, equipment handling, and precision movement. A total of thirteen tasks were used throughout the course of this study.

**Simple Movement**

Four general tasks were completed under this task category: walking forward, walking backwards, vehicular ingress/egress, and the figure-8 duck and run. Walking tasks were completed by having participants move forward and backward (exposure to which direction is performed first was balanced across participants) in a specific area while sighting their gun on a target. During vehicular ingress and egress, participants entered and exited a standard issue law enforcement vehicle. During egress tasks, participants began with the seatbelt fastened, and during ingress tasks, participants ended with the seatbelt fastened. Both self-paced and rapid ingress/egress tasks were completed to simulate everyday motions and motions during emergency situations respectively. Order effects were minimized by balancing the order of exposure to ingress and egress movements. During the figure 8 duck and run task, the bar for them to duck under was first set to their waist height. Participants were then stationed at a starting point, signaled
to go, and ran in a controlled manner underneath the bar. The participants completed a figure 8 pattern around the bar for three complete trials before finally being signaled to stop. This task was also used by Bensel, et al., (1980) during their initial studies into body armor.

**Tactical Movement**

Two tactical movement tasks were studied: egress, move and fire and rapid egress and fire. The egress, move and fire task had three location changes based on auditory cues (Figure 2). The task began with the participant seated inside a standard law enforcement vehicle with hands on the steering wheel and seatbelt fastened, and ended outside of the vehicle with hands on top of the car door. As participants moved from location to location (position 1, position 2, and end), they were verbally instructed to fire on one of three randomly assigned targets. After firing for the last time, participants went to the end position, holstered their weapon, and placed their hands on top of the car door indicating the end of the task. For the rapid egress and fire task, participants began seated with the seatbelt fastened inside a law enforcement vehicle, exited and fired at, again, one of three randomly assigned targets verbally designated by the researcher. After firing at the target, the participant placed both hands on top of the car to signal the end of the task.
Figure 2  Representation of Egress, move, and fire setup

**Equipment Handling**

The tasks in this section were selected to examine how body armor restrictiveness impacted the ability of participants to fire a weapon (using airsoft pellets), holster a weapon, reload a weapon, and access other equipment (e.g., handcuffs). For the weapon fire task, one target was designated for the participant. When directed, the participant drew their weapon, fired at the target, and holstered the weapon. During the weapon reloading, participants drew their weapon, changed out ammunition magazines, and holstered the weapon. The ammunition clip was located in their gun belt. A suspect restraint task was performed using a male 50th percentile dummy (Rescue Randy Combat challenge Model No. 1435, Simulaids, Saugerties, NY). The dummy was placed on its back. When directed, participants had to turn the dummy onto its stomach and handcuffed the dummy using standard zip ties, consistent with current methods as determined by discussions with local police officials.
Precision Movement

The precision movement tasks consisted of a sit/stand and kneel/rise task. The sit/stand task consisted of a seat with no back with a pressure map attached to it. A separate pressure map was also placed in front of the chair. Participants began the task by standing on the floor pressure map, with their back to the seat, and sat only when directed by the researcher. The participant remained seated for 5 seconds and rose. For the kneel/rise task, a pressure map was placed on the floor and designated as the spot that participant to kneel into. The participants were instructed to not take a step forward as they kneel or rise. Instead, they were asked to kneel in such a way that they can kneel and rise using controlled movements. Both knees were required to touch the mat in order to be in a proper kneeling position. The reason why a two-knee, kneeling position was chosen (rather than a traditional one knee up, one knee down kneeling position) was to give participants more stability while wearing external body armor when kneeling. The position was therefore standardized for all armor conditions for consistency. Participants knelt and rose following auditory cues (again following a 5 second delay as with the sit/stand task).

Participants

Twenty participants completed the study protocols and were recruited from two sources: (1) law enforcement personnel (from the Mississippi State University Police Department, Starkville Police Department, and Oktibbeha County Police Department) and (2) the Mississippi State University ROTC chapter or those with military experience. Whenever possible, participants used their issued body armor. However, most ROTC participants did not have issued armor, and therefore armor was provided to them. Due to the limited availability of body armor types, participants were body size restrictions
were instituted to minimize armor fit issues during task performance. Males had to be at least five feet, six inches and weigh no less than 150 pounds. Female participants had to at least be five foot, five inches and weigh no less than 140 pounds. The study provided only one size of CBA and one size of EBA. This was due to the fact that budgetary constraints did not allow the purchase of multiple sets of armor of varying sizes. Whenever possible, participants were encouraged to bring their own armor. This study did not use any other inclusion or exclusion criteria.

**Procedure**

When participants arrived, they were first asked to read and complete an informed consent document approved by the Mississippi State University IRB Board. They were asked to remove their shoes and change into t-shirt and shorts, complete a standard demographic questionnaire, and completed a standard warm up procedure. The warm up consisted of shoulder shrugs, light arm swings, circular head movement, lateral head movement, standing hip circles, side stretches, and toe touches. A researcher led participants through the warm up, instructing them to not strain as they moved through the warm up exercises. After the warm up, participants were outfitted with data collection equipment and trial-appropriate armor. Participants were given up to 5 minutes to move around in the armor to become accustomed to wearing it. After all tasks were completed for that armor condition, participants had data collection equipment removed as needed, and the new armor condition set up (i.e., armor donned, data collection equipment added, and 5 min familiarization period). This process continued until all armor conditions were completed, with data collection equipment checked.
between each condition for signal fidelity and location. Once all armor conditions were completed, participants were debriefed and given water.

**Data Analysis**

Appropriate descriptive statistics were computed for all dependent variables. A two factor repeated measures ANOVA was used to assess the effects of armor configuration and trial on the dependent variables. Tukey’s HSD post hoc tests’ was used for significant results. Correlations between the dependent variables were computed. All analyses were performed on SAS 9.1 and all findings considered significant at an alpha level of 0.05.
CHAPTER IV

RESULTS

Descriptive Statistics and Trial Results

In general, the descriptive statistics showed that as the armor became heavier, it took longer for participants to complete the tasks and heart rate increased (Table 1). The EBA condition also was higher for all of the COP measurements, revealing that participants were affected the most by this particular armor condition when compared to the others (Table 1).

Table 1  Descriptive statistics

<table>
<thead>
<tr>
<th>Armor Condition</th>
<th>Dependent Variable</th>
<th>Mean</th>
<th>Stdv.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time (sec)</td>
<td>6.01</td>
<td>5.28</td>
<td>.44</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>ΔHR</td>
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<td>15.95</td>
<td>2.71</td>
<td>82.44</td>
</tr>
<tr>
<td></td>
<td>%Incr</td>
<td>16.55</td>
<td>8.23</td>
<td>-2.46</td>
<td>41.22</td>
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<tr>
<td></td>
<td>%DiffMax</td>
<td>43.45</td>
<td>24.24</td>
<td>-6.57</td>
<td>137.65</td>
</tr>
<tr>
<td>No Armor</td>
<td>Sit/Stand COP H</td>
<td>-0.62</td>
<td>1.62</td>
<td>-6.37</td>
<td>5.65</td>
</tr>
<tr>
<td></td>
<td>Sit/Stand COP V</td>
<td>-0.67</td>
<td>1.28</td>
<td>-4.29</td>
<td>4.82</td>
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<td></td>
<td>Kneel/Rise COP H</td>
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<td>7.95</td>
</tr>
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<td>-7.97</td>
<td>6.63</td>
</tr>
<tr>
<td></td>
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<td></td>
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<td>CBA</td>
<td>Sit/Stand COP H</td>
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<td>1.26</td>
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<td>5.44</td>
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<td>29.84</td>
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<tr>
<td></td>
<td>ΔHR</td>
<td>38.70</td>
<td>17.60</td>
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<td>20.02</td>
<td>8.97</td>
<td>2.68</td>
<td>55.53</td>
</tr>
<tr>
<td></td>
<td>%DiffMax</td>
<td>54.19</td>
<td>30.40</td>
<td>7.15</td>
<td>182.65</td>
</tr>
<tr>
<td>EBA</td>
<td>Sit/Stand COP H</td>
<td>0.34</td>
<td>1.35</td>
<td>-10.25</td>
<td>6.11</td>
</tr>
<tr>
<td></td>
<td>Sit/Stand COP V</td>
<td>-0.12</td>
<td>1.30</td>
<td>-4.90</td>
<td>5.64</td>
</tr>
<tr>
<td></td>
<td>Kneel/Rise COP H</td>
<td>0.23</td>
<td>2.53</td>
<td>-7.97</td>
<td>7.13</td>
</tr>
<tr>
<td></td>
<td>Kneel/Rise COP V</td>
<td>-3.84</td>
<td>1.53</td>
<td>-6.77</td>
<td>-1.41</td>
</tr>
</tbody>
</table>
Armor condition was found to have significance during the trials in three out of four of the COP conditions (Table 2). When it came to the horizontal COP sit/stand condition, armor condition had no significance. When it came to task completion time, armor condition was also found to have no significance on trial results (Table 2).

<table>
<thead>
<tr>
<th>Dependant Variable</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal COP Sit/Stand</td>
<td>.105</td>
</tr>
<tr>
<td>Vertical COP Sit/Stand</td>
<td>.007</td>
</tr>
<tr>
<td>Horizontal COP Kneel/Rise</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Vertical COP Kneel/Rise</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Task Completion Time</td>
<td>.631</td>
</tr>
</tbody>
</table>

**Mixed ANOVA Results**

**Center of Pressure**

Figures 3 – 5 provide a representative illustration of COP measure changes over the course of a single trial for each body armor condition studied. Spikes in the horizontal and vertical components indicate a more right or forward COP respectively. A near steady line leading to the peaks means that the participant was not engaging the mat.
Figure 3  Representative COP changes for a single participant for a single trial during the sit/stand task in the No Armor Condition

Figure 4  Representative COP changes for a single participant for a single trial during the sit/stand task in the CBA condition
Vertical and horizontal COP components for both the sit/stand and kneeling tasks were affected by armor condition (Table 3). During the sit/stand task, the EBA condition was shown to have a higher horizontal (or right leaning) COP than the other armor conditions. The EBA condition for the sit/stand task resulted in the highest vertical (or forward leaning) COP component, followed by the CBA and the no armor condition (Table 5). For the kneeling task, the CBA condition resulted in the left most horizontal COP measurement, while the no armor condition resulted in the forward most COP measurement (Table 5). Figures 6 and 7 illustrate these results.
Table 3  Repeated Measures Anova Results for Armor Conditions

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Effect</th>
<th>DF</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal COP</td>
<td>Armor Condition</td>
<td>2</td>
<td>06.89</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Sit/Stand</td>
<td>Armor Condition</td>
<td>9</td>
<td>&lt;.001</td>
<td></td>
</tr>
<tr>
<td>Vertical COP</td>
<td>Armor Condition</td>
<td>2</td>
<td>5.89</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Sit/Stand</td>
<td>Armor Condition</td>
<td>2</td>
<td>9.80</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Horizontal COP</td>
<td>Armor Condition</td>
<td>2</td>
<td>1.66</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Vertical COP</td>
<td>Armor Condition</td>
<td>2</td>
<td>66.63</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Kneeling</td>
<td>Armor Condition</td>
<td>2</td>
<td>2.74</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>.HR</td>
<td>Armor Condition</td>
<td>2</td>
<td>2.32</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>.Incr</td>
<td>Armor Condition</td>
<td>2</td>
<td>3.12</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>.DiffMax</td>
<td>Armor Condition</td>
<td>2</td>
<td>88</td>
<td>.41</td>
</tr>
<tr>
<td>Task Completion</td>
<td>Armor Condition</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>completion time</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4  Tukey’s Pair-Wise Comparison for Sit/Stand Cop Results

<table>
<thead>
<tr>
<th>Factor</th>
<th>Horizontal Mean</th>
<th>t-Grouping</th>
<th>Vertical Mean</th>
<th>t-Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBA</td>
<td>.36</td>
<td>A</td>
<td>EBA</td>
<td>-.11</td>
</tr>
<tr>
<td>CBA</td>
<td>.07</td>
<td>A</td>
<td>CBA</td>
<td>-.20</td>
</tr>
<tr>
<td>No armor</td>
<td>-0.60</td>
<td></td>
<td>No armor</td>
<td>-0.66</td>
</tr>
</tbody>
</table>

Means with same letter are not significantly different

Table 5  Tukey’s Pair-Wise Comparison for Kneeling Cop Results

<table>
<thead>
<tr>
<th>Factor</th>
<th>Horizontal Mean</th>
<th>t-Grouping</th>
<th>Vertical Mean</th>
<th>t-Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBA</td>
<td>0.61</td>
<td>A</td>
<td>No armor</td>
<td>-.033</td>
</tr>
<tr>
<td>EBA</td>
<td>0.26</td>
<td>A</td>
<td>CBA</td>
<td>-0.71</td>
</tr>
<tr>
<td>No armor</td>
<td>0.05</td>
<td>B</td>
<td>EBA</td>
<td>-1.05</td>
</tr>
</tbody>
</table>

Means with same letter are not significantly different
Heart Rate and Time Results

Change in heart rate, percent increase in resting, and difference in percent of maximum was shown to be affected by armor condition, though task completion time was not affected (Table 3). Change in heart rate was significantly higher for the EBA
armor condition when compared to the other armor conditions, while the CBA and no armor conditions did not differ (Table 6). Figures 8-10 illustrate these findings.

Table 6  Tukey’s Pair-Wise Comparison for ∆HR Results

<table>
<thead>
<tr>
<th>Factor</th>
<th>ΔHR Mean</th>
<th>t-Grouping</th>
<th>%Incr Mean</th>
<th>t-Grouping</th>
<th>%DiffMax Mean</th>
<th>t-Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBA</td>
<td>38.27</td>
<td>A</td>
<td>19.71</td>
<td>A</td>
<td>53.29</td>
<td>A</td>
</tr>
<tr>
<td>CBA</td>
<td>33.16</td>
<td>B</td>
<td>17.10</td>
<td>B</td>
<td>46.45</td>
<td>B</td>
</tr>
<tr>
<td>No Armor</td>
<td>32.06</td>
<td>B</td>
<td>16.56</td>
<td>B</td>
<td>44.05</td>
<td>B</td>
</tr>
</tbody>
</table>

Means with same letter are not significantly different

Figure 8  Change in heart rate
Figure 9  Percent difference in heart rate

Figure 10  Difference in percent maximum of heart rate
CHAPTER V
DISCUSSION AND CONCLUSIONS

The purpose of this study was to evaluate the effects of body armor design during simulated law enforcement tasks. In general, the external armor condition was found to differ from the concealable and the no armor condition.

The results for the center of pressure tasks were mixed. The results of the data suggested a bias towards participants putting more pressure on their right knee instead of being more evenly distributed during the kneeling task. One possible explanation for this result is the task itself. Typically, officers are trained to only assume a single knee stance to ensure mobility. For the kneeling task, participants were told to assume a two knee position to aid in stability of the task due to armor weight. However, in preparation for movement, the officers may not have balanced themselves on both of their knees, but rather their dominant knee (the right in this case). Also, the right side skewness of the COP data may have resulted during the rising portion of the kneeling task, where additional pressure was placed on the right knee at the start of the rise. The vertical component results for the kneeling task were consistent. The no armor condition found participants leaning forward there most, while the CBA and EBA armor conditions had participants leaning backwards more in both tasks. This is logical as the weight of the armor naturally makes the upper body heavier, causing the upper torso to lean forward. The body compensates by trying to assume a more upright posture, thereby putting more force backwards. The chair design may have affected the posture assumed while sitting.
Since the chair had no backrest, participants may have leaned forward more to minimize the risk of falling backwards while seated. The horizontal component results of the sit/stand task revealed a right-sided biasness. The no armor condition had participants leaning the most towards the left, while the CBA and EBA armor conditions were more towards the right (i.e., a more centered sitting posture). It is not clear why participants may have leaned more towards the right during sitting. The horizontal component revealed no significant differences between the EBA and CBA conditions on participants as they performed the task. However, there were significant differences between the no armor condition and the other conditions, as it had the most left-sided bias out of the armor conditions.

Varied COP results may have resulted from a “lack of fit” of the armor conditions. Law enforcement and military personnel are issued armor designed to fit their body type. In this study, participants did not always have issued armor and, therefore, had to be supplied armor by the researchers. Therefore, it is possible that participants may have altered their posture and positions during this task to compensate for armor that was not a true fit.

Change in heart rate due to armor conditions was found to only significantly apply in the case of wearing the EBA body armor. This was the same result for the percent increase in resting heart rate and difference in percent maximum of heart rate as well. This is most probably due to added bulkiness and weight of the EBA body armor. This armor adds weight to participants and that extra weight increasing the energy expenditure of the participants.

It was surprising that no task completion time differences were found, particularly for the EBA armor condition. This finding could be due to two reasons. First,
participants were, for the most part, trained in performing activities while wearing external body armor and therefore have learned how to compensate for that (e.g., work harder to minimize performance effects). Second, as these tasks were short in duration and in general not physically demanding, it may be unlikely that time differences could be identified. Longer duration tasks however could possibly result in different finding. However, it is important to also note that since the tasks selected for this study are short in duration, the resulting non-significance finding is still important. It may be that longer duration tasks, different from those selected for this study, will result in significant performance effect between the armor conditions.

The study has been able to show that there is evidence that wearing body armor can significantly affect the performance of wearers. When it came to sitting and kneeling, the addition of body armor to participants’ bodies made the participant have to shift their COP. This implies that the addition of body armor, be it concealable or external, has a significant effect on the way that an individual moves. Heart rate was also shown to have been affected by the external armor condition, increasing with some level of significance from that of the other armor conditions. More in-depth study on the CBA and EBA armors may yield greater information as to the cause of the significance. The use of a variety of armor sizes that would accommodate size issues would help to identify exactly how significantly body armor (of all types) affects the performance of those that wear them. The use of force plates in the armor as well would also allow researchers examine the impact of the armor on the body as they are worn. Even today, the performance measures that are used in the United States are the ability to stop ballistic projectiles and environmental wear and tear. There are still no tests of task efficacy/accuracy within the performance tests/standards used in the United States. This
study was an examination of whether or not there was any evidence that the ability to perform physical tasks was in any way significantly affected by the wearing of body armor. This study has shown that there is merit to the belief that wearing body armor does affect the physical performance of the wearer. Since there is evidence that wearers of body armor are affected in terms of their physical performance, this lends credence that the inclusion of ergonomic measures when it comes to body armor performance measures should be considered by body armor companies, national and local law enforcement agencies, and the National Institute of Justice
REFERENCES


