HHS Public Access
Author manuscript
Ergonomics. Author manuscript; available in PMC 2024 September 12.

Published in final edited form as:
Ergonomics. 2024 April ; 67(4): 541–565. doi:10.1080/00140139.2023.2232581.

Association of anthropometric characteristics of law enforcement officers with perceived ratings of fit, comfort, and pain in the use of body armor

Hongwei Hsiao[a,b]

[a]Texas A&M University, Corpus Christi, TX, USA

[b]National Institute for Occupational Safety and Health (NIOSH), Morgantown, WV, USA

Abstract

Knowledge gaps exist on association between law enforcement officer (LEO) anthropometric characteristics and perceived body armour fit, armour discomfort, and armour-caused pain. This study assessed the correlation and identified influential torso dimensions for armour sizing and design applications. Nine-hundreds and seventy-four LEOs across the U.S. participated in a national study on LEO armour use and body dimensions. Perceived ratings of armour fit, armour discomfort, and body pain were found moderately correlated with each other. In addition, armour fit ratings were associated with certain torso anthropometric characteristics, such as chest circumference, chest breadth, chest depth, waist circumference, waist breadth (sitting), waist front length (sitting), body weight, and body mass index. LEOs who reported armour poor fit, armour discomfort, and armour-caused pain had a larger mean of body dimensions than the "armor good fit" group. More women than men had poor fit, discomfort, and body pain in the use of body armour.

Practitioner summary:

The identified influential body measurements can be used as the "drivers" for multivariate analyses to develop an improved armour sizing system to further LEO protection. The study also suggests consideration of gender specific armour sizing systems to accommodate differences in torso configurations between male and female officers and to resolve the concern that more female officers had poor armour fit than male officers.

Keywords

Police; body size; body armour; armour fit; vest; torso

CONTACT Hongwei Hsiao hongwei.hsiao@tamucc.edu Texas A&M University, 6300 Ocean Dr., Corpus Christi, TX 78412, USA.

1. Introduction

Law enforcement officers (LEOs) were among the four occupations with an injury incidence rate greater than 400 cases per 10,000 full-time workers in 2011–2015 in the United States (U.S. Bureau of Labor Statistics 2016). Of these injuries to LEOs, 27% were associated with violent acts. In addition, during 2003–2009, 968 officers died in the line of duty and 44% of the fatalities were related to violent incidents (Tiesman et al. 2013). The most recent data showed an increase of incidents with 129 officers died in the line of duty in 2021 and 57% of them were killed feloniously (Federal Bureau of Investigation (FBI)) 2022a). Moreover, the Federal Bureau of Investigation (FBI) reported that more than 56,034 officers were assaulted out of the 475,848 employed officers in 2019, which is equivalent to 11.8% (Federal Bureau of Investigation (FBI) 2022b). Body armour (Figure 1(a)), typically in a vest form, is important equipment for personal protection of LEOs against many types of assaults, such as handgun and rifle ammunition, knives, and spikes (Greene 2019).

1.1. Types of body armour

Two types of ballistic resistant armour are used by LEOs to protect their vital organs, such as heart, liver, lungs, spleen, and kidneys. Soft body armour is the type of body armour that officers typically wear during their daily duties and is referred to as a ‘vest’. Usually, a vest consists of two ballistic resistant panels held in place on the wearer’s torso by a carrier (a plate-holding pouch). One panel protects the front of the torso, the other safeguards the back of the torso (Figure 1(b)). The vest is worn with the front panel overlapping the back panel to protect the sides of the torso (National Institute of Justice (NIJ)) 2014). The front panel and back panel themselves typically consist of an enclosure that holds the ballistic resistance materials (Figure 1(c)). The ballistic resistance materials can be in multiple layers. A vest can be worn under an officer’s uniform or over a uniform. It is called concealable armour when it is worn under a uniform. Hard armour consists of a rigid plate of ballistic-resistant materials to offer greater protection against higher threats than soft armour. Often, a rigid plate is added in soft armour to form hard armour; some hard armour plates are designed to be used by themselves in a carrier as hard armour as well. Hard armour is used by officers for entering high-risk situations and thus is not typically worn for extended periods (National Institute of Justice (NIJ)) 2014).

Law enforcement body armour originates from military armour but is slightly different from military full body tactical armour and a bullet resistant military plate carrier. The military full body tactical armour consists of front, side, and back panels in a ‘vest’. The vest can be joined with a helmet and arm and leg protection components to form a full body protection. A bullet resistant military plate carrier is lighter than a military full-body armour vest and can hold soft or hard plates to provide different levels of protection required. LEO vests build on this concept.

1.2. Body armour sizing, fit, and comfort

Since the first performance standard for ballistic resistant police body armour was published in 1972 (National Institute of Law Enforcement and Criminal Justice 1972), research on the impact of body armour has advanced and a certification process of LEO body armour has been in place in U.S. for some years (Greene 2019). The research and recommendations on *body armour sizing and fit,* however, have not progressed at the same level, possible due to lack of national LEO anthropometry data and information on their correlation with body armour fit and comfort. In a national questionnaire survey (N = 1027), the National Institute of Justice (NIJ; National Institute of Justice 2012) reported that 58.6% officers were satisfied with the fit of their body armour while 29% of officers reported being dissatisfied, although they were fitted by armour manufacturers or their internal agency representatives. 12.4% of officers reported neutral with their body armour fit (Grant et al. 2012). 'When officers were asked which features they want to see in the next generation of body armor, the most common responses were improved comfort (84.4%), improved fit (72.6%) and reduced weight (63.9%)' (Grant et al. 2012). With an understanding that officers who did not routinely wear body armour suffered 3.4 times more fatal injuries from a torso shot than officers who routinely wear body armour (LaTourrette 2010), the authors (Grant et al. 2012) pointed out that more comfortable body armour could increase the likelihood that officers will regularly use their body armour.

While body armour fit, perceived comfort of armour, and human body characteristics have been explored in the military settings (Gordon, Corner, and Brantley 1997; Choi et al. 2018; Tavares et al. 2020; and Coltman et al. 2021), studies of occupational law enforcement officer anthropometry and their armour fit remain limited. With a goal to lessen the gap in body armour coverage and fit, Robinson and Horlick (2018) conducted 'interviews, observations, workshops, and studies involving hundreds of officers', and concluded that 'there are still many unknowns in armor fit and coverage, especially how body measurements are turned into body armors'. They suggested a collaborative effort among stakeholders to further study the armour fit and coverage problems and define solutions by possibly including 3-dimensional (3D) body scanning, standardising sizing across the industry, certifying measurers/fitters, and implementing body armour management programs.

1.3. Knowledge gaps in armour sizing, officer anthropometry, and gender effect

The American Society for Testing and Materials (ASTM) E3003–20 standard 'Body Armor Wearer Measurement and Fitting of Armor' provided guidance on body measurement technique and assessment of armour fit and torso coverage for soft ballistic-resistant and stab-resistant armours (ASTM (American Society for Testing and Materials) International 2020). With the focus on training individuals on proper measurement techniques and fitting of body armour, the standard does not cover information on relationship of these measurements with armour sizing.

Recognising that armour fit is a multi-dimensional matter, some armour manufacturers have developed adjustable sizing vests (Figure 2) to help officers in deciding their armour front- and back-panel sizes. The ASTM E3003–20 standard section seven describes the procedure on the use of a sizing vest. The configuration (i.e., dimensions and number of sizes) of sizing vests and adjustment range of each vest component, however, are not covered in the standard.

A recent literature review and market survey conducted by the National Institute for Occupational Safety and Health (NIOSH) found no consistent, commonly used body dimensions, LEO armour sizing structure, and sizing selection criteria in the U.S. armour marketplace. Adding complexity to sizing and fit of body armours, LEOs were reported to be on average larger in body dimensions than the civilian population and military personnel (Hsiao et al. 2021). No information in the literature was identified on what anthropometric databases were used in specifying LEO armour dimensions in the current marketplace. Moreover, the most recent national LEO anthropometry study conducted by NIOSH (Hsiao et al. 2021) reported that previous best available LEO anthropometry data were collected 46 years ago (Martin et al. 1975). Based on the most recent data collected by NIOSH, the mean values of LEO body dimensions have increased over the past 46 years by 120 mm in waist circumference, 90 mm in chest circumference, 26 mm in chest width, and 12.2 kg in body weight for males. No previous data was available for comparison for females. Furthermore, body armour has been primarily designed for men. With more women joining the law enforcement workforces, wearability of body armour for female officers has been a subject matter in discussion by the protective gear fit research, design, and manufacturing entities.

Finally, given that personal protective equipment (PPE) sizing and design (such as officer body armour) is a multivariate process, use of a single measurement or a few dimensions additively to define the fit and sizing structure is known to be deficient (Hsiao 2013). Two important steps can be made to further armour design, sizing, and fit for better LEO protection: (1) an investigation of national LEO torso anthropometry by gender and (2) a systematic assessment of armour fit, perceived armour discomfort, and armour-caused body pain and their association with LEO torso anthropometric characteristics.

1.4. Objective

This study investigated the state of LEO-armour interface by identifying the association among LEO torso anthropometric characteristics, LEO armour fit, armour discomfort, and armour-caused body pain for armour sizing and design application. The focus is on soft armour as it is the type of body armour that officers typically wear during their daily duties. It was hypothesised that (1) the perceived ratings of LEO armour poor fit, armour discomfort, and armour-caused body pain are correlated with each other, and (2) LEO body characteristics (e.g., gender and body dimensions) have an effect on body armour comfort and fit ratings and perceived body armour-caused body pain. The study results will ascertain most influential torso dimensions associated with armour fit to LEOs, which will be used as the 'drivers' for a series of multivariate cluster analyses to establish improved armour-sizing structures and representative LEO torso models for armour design.

2. Methods

2.1. Participants

A total of 974 LEOs (756 men and 218 women) participated in the study conducted by the National Institute for Occupational Safety and Health (NIOSH) from 2018 to 2020. Their demographic information was recorded (Table 1; Hsiao et al. 2021) and their torso dimensions relevant to body armour design and sizing were measured (Table 2). Participants also answered 4 survey questions relevant to fit of armour, discomfort of armour, armour-caused body pain areas, and needs for body-armour-fit improvement.

The LEO participants were recruited based on the geographic density of racial/ethnic distributions, derived from the 2010 U.S. Census (U.S. Census Bureau 2012). The research protocol, questionnaire, and participant consent form were approved by the NIOSH Institutional Review Board (IRB #14-DSR-02XP). In addition, the study questionnaire, sampling plan, and protocol were approved by the U. S. Office of Management and Budget (OMB #0920–1232).

2.2. Procedure

As part of a national LEO anthropometry study, a sample of LEOs participated in data collection with a NIOSH mobile trailer at one of 12 study sites across the United States in 2018–2020 (Hsiao et al. 2021). The LEOs read and signed a consent form to participate in the study and completed a demographic data form, which comprised sex, age, and race/ethnicity. Two anthropometry data collection specialists from a 4-member team then measured their body dimensions (Table 2). Two three-dimensional (3-D) body scans (standing and seated) of the participants were also conducted using a 3-D Cyberware WBX whole body scanner (Cyberware Inc., Monterey, California). The participants then answered 17 questions on a tablet computer, which assessed the state of LEO-vehicle and LEO-equipment interfaces. Finally, the participants were reimbursed for their time and dismissed. Four of the 17 questions relevant to body armour fit, armour comfort, armour-caused body pain areas, and areas for armour design improvement along with their anthropometric data are included in this paper. Thirteen of the 17 questions related to vehicle use were reported in a separate article (Hsiao 2023). Low response rate and missing data were common problems with questionnaire surveys (Lindemann 2021). This stratified sampling survey integrated the questionnaire survey in an in-person anthropometry measurement section, which resolved the concern of low response rate in typical customer surveys.

The four survey questions on body armour fit, armour comfort, armour-caused body pain areas, and areas for armour design improvement are summarised below:

1. Rate the fit of your body armour (1 = extremely poor fit, 2 = poor fit, 3 = neutral, 4 = good fit, and 5 = excellent fit).

2. Rate the comfort of your body armour (1 = very uncomfortable, 2 = uncomfortable, 3 = neutral, 4 = comfortable, 5 = very comfortable).

3. Does the body armour cause discomfort or pain on particular areas of the body? If yes, tick the areas (neck, underarm, chest, waist, hips, and other – write in)

4. What areas of body armour fit should be improved? (neck, underarm, chest, waist, hips, other – write in, none).

A five-point Likert scale was used in the first two questions related to LEO body armour fit and comfort. Both questions have positive and negative declarations (i.e., poor fit vs. good fit and uncomfortable vs. comfortable) on the same scale. Specifically, the ratings of fit of LEO body armour were 1–5, verbally anchored as extremely poor fit, poor fit, neutral, good fit, and excellent fit. The ratings of comfort of LEO body armour were also 1–5, verbally anchored as very uncomfortable, uncomfortable, neutral, comfortable, and very comfortable. Officers rated the armour they used at the time of data collection. They were typically fitted by armour manufacturers or their internal agency representatives for their armour and have used the same armour for at least a few months.

In typical business satisfaction and dissatisfaction surveys (such as job surveys), satisfaction and dissatisfaction are two independent constructs. Dissatisfaction can be related to company policies and/or salary. Satisfaction would be related to the work context and personal growth potential (Herzberg, Mausner, and Snyderman 1959). Similarly, in work environment comfort and discomfort evaluations, discomfort was reported to be related to physical characteristics of an environment (Zhang, Helander, and Drury 1996), of which the absence of discomfort, nothing is experienced. To notice comfort, more should be experienced, such as luxury, safety, relaxation, or well-being; therefore, comfort and discomfort are considered two independent constructs. In product evaluation (such as body armour), however, both discomfort and comfort can be related to product physical features (Noro et al. 2012; de Korte et al. 2012) although comfort may also include the aesthetics of design (De Looze, Kuijt-Evers, and Van Dieën 2003; Vink and Hallbeck 2012), where one rating construct is often used. In our armour fit and comfort study, poor fit and discomfort of armour as a personal protective device would be unaccommodating of the armour to LEOs. The absence of poor fit or discomfort can be ‘Neutral’ or ‘fit and comfort’ The use of a 5-point Likert scale with both positive and negative declarations (i.e., good fit vs. poor fit and comfortable vs. uncomfortable) on the same scale is practical. The scaling method offered an option for a one-way ANOVA analysis to compare anthropometric differences among poor fit (rating of 1 or 2), neutral (rating of 3), and good fit (rating of 4 or 5) groups. In addition, the scaling method allowed us to roll the neutral group into good fit group for two-group *t*-test comparisons, which can be a choice in overcoming small sample size concern in three-group analyses for female LEOs. In other words, classifying the study participants into armour poor fit (extremely poor to poor; rating of 1 and 2) vs. armour good fit (neutral, very good, and excellent; rating of 3, 4, and 5) groups as well as discomfort of armour (very uncomfortable to uncomfortable; rating of 1 and 2) vs. comfort of armour (neutral, comfortable, and very comfortable; rating of 3, 4, and 5) groups in data analyses to identify contributing torso dimensions to the armour accommodation is a choice for female LEOs due to their smaller sample size ($N = 218$) as compared to male LEOs ($N = 756$).

3. Statistical analyses

Two-tail *t*-tests were performed for 11-paired body-dimension comparisons between men and women, with $p = .05/11 = .0045$ ($z = 2.61$) as the adjusted significant level. Chi-square analyses were performed to differentiate the distribution of armour fit, amor comfort, and armour-caused body pain between male and female officers.

A bivariate fit/plot of perceived body armour fit by body armour comfort was performed. Pearson correlation coefficient (r) was used to define the level of correlation between *armour* *fit* and *armour comfort*. A regression analysis also was conducted to verify that the perceived armour comfort rating is a predictor of body armour fit.

One-way ANOVAs with Tukey–Kramer HSD all-pairs comparisons of means for each LEO body dimension among the three armour fit groups (poor, neutral, and good) were performed for male LEOs to determine the differences in torso anthropometry among the three armour fit groups. Same one-way ANOVAs with Tukey–Kramer HSD all-pairs comparisons of means for each LEO body dimension among the three armour comfort groups (uncomfortable, neutral, and comfortable) were also performed for male LEOs. For female LEOs, *t*-tests were performed to identify the difference in means of each LEO body dimension between the two armour fit groups (poor fit group vs. good fit + neutral group). The decision to use two-group comparisons in lieu of three-group one-way ANOVA for female LEOs was to resolve the concern of small sample size of female LEOs in a three-group one-way ANOVA. Similarly, *t*-tests were performed to identify the difference in means of each LEO body dimension between the two armour comfort groups (uncomfortable group vs. comfortable + neutral group). More details of statistics analyses are presented in the Results section.

4. Results

4.1. LEO anthropometry, armour fit, and armour comfort

Data for 11 body dimensions relevant to LEO body armour configuration are presented in Table 3. Since our sample outcomes by gender, racial/ethnic, and age are very close to the original sampling plan, we elected to use unweighted data in this paper for simplicity. The data in 11-paired two-tail t-test comparisons indicate significant differences in means between male and female officers for all 11 dimensions.

Overall, 26.2% of LEOs rated their armour poor fit (extremely poor to poor – rating of 1 or 2); 30.2% of participants rated Neutral (rating of 3) and 43.6% of LEOs ranked the armour good fit (good to excellent – rating 4 or 5) (Table 4). A Chi-square analysis shows that more proportion of female officers (38.7%) than male officers (22.4%) rated their armour poor fit which is significantly different (Pearson $\chi^2_{(2, N=784)} = 25.27$, $p < .0001$).

Overall, 29.7% of LEOs in the study sample found their body armour comfortable (comfortable to very comfortable – rating of 4 or 5) and 38.4% LEO reported Neutral for their body armour. 31.9% of LEOs rated their armour uncomfortable (from very uncomfortable to uncomfortable – rating of 1 or 2) (Table 5). There was a disparity in the perceived discomfort of the body armour between men (28%) and women (45%). A Chi-square analysis confirms that the disparity is statistically significant (Pearson $\chi^2_{(2, N=821)} = 20.96$, $p < .0001$).

A bivariate assessment of perceived body armour fit by body armour comfort showed that the Pearson correlation coefficient (r) between *armour fit* and *armour comfort* was 0.565 with 95% confidence interval of (0.514, 0.612), $p < .0001$ (Figure 3), which indicated a moderate positive correlation ($0.5 < r < 0.75$) between armour fit and armour comfort. A regression analysis also confirms that the perceived armour comfort rating is a predictor of body armour fit ($F_{(1, N=747)} = 349.24$, $p < .0001$). Figure 3 includes nonparametric density contours to demonstrate patterns in point density where the scatterplot is darkened by significant number of points in the rating range of 2, 3, and 4 for body armour fit and body armour comfort.

4.2. Body armour-caused pain and needed armour-fit improvements

More than a half of LEOs (54.3%) reported that body armour caused discomfort or pain in at least one body area, more so for women (68.5%) than men (50.2%), which is significantly different between the two groups (Pearson $\chi^2_{(1, N=889)} = 20.88$, $p < .0001$). LEOs who rated armour 'good fit' (good fit or excellent fit) tended to report that body armour did not cause body area discomfort/pain than who rated armours 'neutral' or 'poor fit' (poor or extremely poor) (Pearson $\chi^2_{(2, N=776)} = 54.35$, $p < .0001$). This reaffirms that while a good fit of an armour is not a guarantee of no armour-caused discomfort/pain in all body areas, the association between armour fit and body area pain is evident. For both male and female officers, body armour caused body pain mainly in the neck and underarm areas. The third most affected area was the chest for women and waist for men (Table 6).

LEOs also reported the need for armour-fit improvements. About 69.2% LEOs indicated a need for fit improvement for at least one armour area. More women (79%) suggested armour fit improvement than men (66.3%), which is significantly different (Pearson $\chi^2_{(1, N=883)}=11.66$, $p < 0.001$; Table 7). For men, the most needed fit improvements were waist/stomach area (14.9%), side area (14.3%), and armour sizing (10.4%). For women, the most needed fit improvements were chest area (45.0%), waist/stomach area (15.0%), and side area (10.5%). For men and women combined, the most needed fit improvements were chest area (25.0%), waist/stomach area (21.5%), side area (19.4%), and armour sizing (13.7%).

4.3. Correlation among body dimensions, armour fit, armour comfort, and body pain

4.3.1. Body dimensions and body armour fit—One-way ANOVA of each of the 11 body dimensions using body armour fit category (poor fit – rating of 1 or 2, neutral – rating of 3, and good fit – rating of 4 or 5) as the independent variable is summarised in Table 8. For male officers, those who reported poor fit of armour had a larger mean than the good fit group for chest breadth (Diff = 16 mm, $p < .0001$), chest circumference (Diff =47 mm, $p < .0001$), chest depth (Diff =13 mm, $p < .0001$), waist breadth (Diff = 18 mm, $p < .0001$), waist circumference (Diff = 57 mm, $p = .0001$), waist front length sitting (Diff =10 mm, $p =.0074$), weight (Diff =9 kg, $p < .0001$), body mass index (Diff =2.26, $p < .0001$), and front lateral length (Diff = 10 mm, $p = .009$).

Given the small sample size ($N = 218$) of female LEOs, one-way ANOVA of each of the 11 body dimensions with Tukey–Kramer HSD all-pairs mean comparisons among the three armour fit groups (poor fit, neutral, and good fit) may not be sensible, the neutral group was rolled into the good fit group for t-tests. Those who reported *poor fit of armour* had a larger mean than the *good fit of armour* (including neutral) group for chest breadth (Diff = 10 mm, $p =.0318$), chest circumference (Diff =40 mm, $p = .0101$), chest depth (Diff = 13 mm, $p = .0142$), waist breadth (Diff = 14 mm, $p = .0288$), waist circumference (Diff = 42 mm, $p = .0360$), and body mass index (Diff = 1.6, $p = .0218$) (Table 9). The *poor fit of armour* group, however, had a smaller mean of stature (Diff = 21 mm, $p = .0247$) than the good fit (including neutral) group.

4.3.2. Body dimensions and armour comfort—Overall, 29.7% of participants rated their armour *comfortable* (rating of 4 or 5) while 31.9% reported *uncomfortable* (rating of 1 or 2). 38.4% of LEOs rated their armour comfort *neutral* (rating of 3). Women (45.0%) had more uncomfortable rating (1 or 2 rating) than men (28%) with their armour (Pearson $\chi^2_{(1, N=821)} = 19.28$, $p < .001$). The ratings are correlated to some body dimensions.

For male LEOs, those who reported uncomfortable with their armour (including very uncomfortable and uncomfortable groups) had a larger mean than the comfortable with armour group (including comfortable and very comfortable groups) for chest breadth (Diff = 18 mm, $p < .0001$), chest circumference (Diff = 48 mm, $p < .0001$), chest depth (Diff = 13 mm, $p < .0001$), waist breadth (Diff =14 mm, $p < .0001$), waist circumference (Diff = 48 mm, $p = .001$), waist front length (Diff = 8 mm, $p = .0367$), weight (Diff = 8.3 kg, $p < .0001$), body mass index (Diff = 2.0, $p = .0002$), and front lateral length of torso (Diff = 11 mm, $p = .0054$) (Table 10).

The uncomfortable with armour group (including very uncomfortable and uncomfortable groups) also had a larger mean than the neutral group for chest breadth (Diff = 12 mm, $p = .003$), chest circumference (Diff = 30 mm, $p = .006$), chest depth (Diff = 9 mm, $p = .009$), waist breadth (Diff =11 mm, $p = .011$), waist circumference (Diff = 37 mm, $p = .011$), weight (Diff = 4.0 kg, $p < .022$), and body mass index (Diff = 1.4, $p = 0.007$).

Again, given the small sample size ($N = 218$) of female LEOs, one-way ANOVA of each of the 11 body dimensions with Tukey–Kramer HSD all-pairs mean comparisons among the three armour comfort groups (uncomfortable, neutral, and comfortable) may not be sensible. The neutral group was rolled into the comfortable group for t-tests. Those who reported uncomfortable with armour had a larger mean than the comfortable with armour (including neutral) group for chest breadth (Diff = 9 mm, $p =.0273$), chest circumference (Diff = 39 mm, $p = .0053$), chest depth (Diff = 14 mm, $p = .0064$), waist breadth (Diff = 15 mm, $p = .0120$), waist circumference (Diff = 45 mm, $p = .0137$), weight (Diff = 4.4 kg, $p = .0205$), and body mass index (Diff = 1.9, $p =.0038$) (Table 11).

4.3.3. Armour-caused pain in body areas and body dimensions—Overall, 54.3% of participants reported body area *Pain/Discomfort* caused by body armour while 45.7% reported *No Symptom*. More females (68.5%) reported armour-caused pain/discomfort than males (50.2%) (Pearson $\chi^2_{(1, N=889)} = 20.88$, $p < 0.001$). The ratings were associated with certain body dimensions.

For male LEOs, those who reported armour-caused *pain in body areas* had a larger mean than the *No Symptom* group for chest breadth ($t = 3.04$, $p =.002$), chest circumference ($t = 3.11$, $p =.002$), chest depth ($t = 2.41$, $p =.016$), waist breadth ($t = 2.85$, $p = .005$), waist circumference at omphalion $t = 2.52$, $p = .012$), waist-front length ($t = 2.29$, $p = .023$), weight (t = 3.18, p = .002), and body mass index ($t = 2.97$, $p = .003$) (Table 12). For females, those who reported armour-caused *Pain in body areas* had a larger mean than the

No Symptom group for waist circumference at omphalion ($t = 2.06$, $p = 0.041$), weight ($t = 2.26$, $p = 0.025$), and body mass index ($t = 1.98$, $p = .050$) (Table 13).

4.3.4. Body dimensions for armour design and sizing development—

This study showed that poor fit of body armour, uncomfortable with armour, and armour-caused pain at body areas were associated with certain body dimensions (Tables 9–13) which mean that these dimensions play a significant role for improved armour configurations and sizing plans. The outcomes are synthesised and presented in Table 14.

For women, seven dimensions can be considered as important dimensions for armour configuration or sizing as they ‘affect’ at least two of the three perceived ratings of fit, comfort, and pain. The dimensions are chest breadth, chest circumference, chest depth, waist breadth (sitting), waist circumference at omphalion, body weight, and body mass index (BMI). Stature can be considered as an additional dimension as needed.

For men, eight dimensions are considered important dimensions: chest breadth, chest circumference, chest depth, waist breadth (sitting), waist circumference at omphalion, waist front length (sitting), body weight, and body mass index (BMI). These dimensions are defined as having significant impact on all three ratings of armour fit, perceived discomfort, and armour-caused pain among male LEOs. They are marked in bold in Table 14. The results lead to two points. First, the eight key body dimensions for each gender group can be used for multivariate cluster analyses to explore the optimal sizing systems for body armour. Second, it is desirable to develop a body armour sizing structure for female LEOs for two reasons: (1) There is an increasing trend of females in patrolling occupations from 5% in 1980 (Cordner and Cordner 2011) to 17.6% in 2019 (U.S. Bureau of Labor Statistics 2020), and (2) There are distinct anthropometric differences between male and female LEOs (Table 4). In a study on the effect of torso and breast characteristics on perceived fit of body armour among female soldiers ($N = 97$) in Australia, eight torso dimensions (stature, body weight, suprasternale height, chest depth, chest breadth, neck circumference, waist circumference, under/over-bust chest circumference) were significantly different among the three armour fit groups (too small, good fit, and too large) of female soldiers (Coltman et al. 2022). Six of the dimensions were consistent with the results of female LEOs in our study ($N = 218$). In addition, in a study on whether bras can improve the performance of unisex ballistic vests for female LEOs in Australia of all bust sizes ($N = 273$), women with larger breasts experienced more problems with unisex ballistic vests than women with smaller breasts (Niemczyk, Arnold, and Wang 2020). Both studies highlighted the need to consider anthropometry of women (e.g., chest circumference, chest depth, and chest width) in armour design and sizing.

5. Discussion

5.1. LEO anthropometry and body armour panel

Our market survey on LEO body armour in the US found no consistent, commonly used sizing structure and specifications in the marketplace for selecting an armour size. The NIJ Standard 0101.06 (National Institute of Justice (NIJ)) 2008) and Selection & Application Guide 0101.06 to Ballistic-Resistant Body Armour (National Institute of Justice (NIJ))

2014) provide five template sizes to guide armour suppliers to submit their samples *for ballistic resistant tests*. While the Guide stipulates that these templates are not indicative of service armour design (pages 53–57), it indicates that the sizes intend to 'accommodate different shapes and sizes of potential wearers' (page 5) representing 95% of officers (page 14). The guide also recommends that the front and back templates (not just the carriers) of armour panels have a minimum 2-inch (50 mm) overlap at the two sides (page 25). Chest breadth and front lateral length are two determining dimensions in the guide to differentiate the template sizes. The front lateral length is equivalent to the waist-front length used in the anthropometry research community. The scatter plot of waist-front length (sitting) vs chest breadth in Figure 4 exhibits the relationship between the NIJ 0101.06 sizing templates for ballistic-resistant testing and two torso dimensions of U.S. Army soldiers (Defense Centers for Public Health – Aberdeen (DCPH-A)) 2020). The sizing templates match the soldiers' dimensions nicely when the 2-inch (50 mm) overlap at the two sides of a panel is added to chest breath measurements.

The first figure shows the front view of body armour with two attached small tape measures at the front and side of armour when an officer is standing. The second figure shows the same when an officer is seated. The third figure shows back view of body armour with two attached small tape measures at the back and side of armour when an officer is standing.

The scatter plot of waist-front length (sitting) vs. chest breadth of current law enforcement officers (Figure 5), however, shows that the NIJ 0101.06 sizing templates for ballistic-resistant testing are in general smaller than the torso dimensions of current officers, especially in chest width. Since the armour front and back panels are required to have at least 50-mm (2-inch) overlap (National Institute of Justice (NIJ)) 2014), the discrepancy between armour panel dimensions in the NIJ guide – 0101.06 and current LEO body dimensions would be even larger than what Figure 5 has demonstrated.

It is understandable that the panel templates in the NIJ guide – 0101.06 are meant to be samples for ballistic-resistant testing and thus may not represent the real armour design and dimensions.

However, Figure 4 seems to confirm that the existing test panels were built upon the torso dimensions of soldiers, which were the best available data at the time. It is known that LEOs were reported to be on average larger in body dimensions than the civilian population and military personnel (Hsiao et al. 2021). With the availability of LEO torso dimensions, armour manufacturers and armour wearers (along with ASTM standard committees and NIJ) may find it appealing to use the new anthropometric information for both panel template (ballistic-resistant testing samples) development and body armour design in the future to better accommodate different shapes and sizes of potential wearers.

5.2. LEO armour fit, armour comfort, body pain, and body dimensions

This study showed the differences in body characteristics/dimensions among groups with different perceived ratings of armour fit, armour comfort, and armour caused pain. In addition, LEOs reported that armour fit can be further improved in chest area and waist parts for women and waist and side areas for men. Two important messages can be drawn from the results. First, while a fit of body armour is not a guarantee of no discomfort or pain of all body areas, the moderate positive correlation between armour fit and armour comfort ($r = 0.56$) (Figure 3) indicated that improvement of armour fit would improve armour comfort and reduce body area pain during the use of body armour. Second, this survey on LEO comfort with body armour as well as body area pain caused by body armour did not specifically query the weight effect of armour on LEO comfort rating. A LEO physical stressor survey reported that survival time to first-onset lower back trouble was affected adversely by wearing body armour weighing approximately 8.5 kg (Burton et al. 1996). On the other hand, a study (N=11) on three types of body armour vests (4.12 ± 0.65 kg, 3.54 ± 0.70 kg, and 3.24 ± 0.48 kg) along with 8.69 ± 0.68 kg duty belt load, as compared to wearing a normal station uniform with 8.69 ± 0.68 kg duty belt load, did not appear to hinder policing tasks (Schram et al. 2019). With the conflicting results in the literature, the optimal or maximum acceptable weight of body armour warrants a further study.

Moreover, officers reported that body armour-caused body pain mainly occurred in the neck and underarm areas. The third most affected area was the chest for women and waist for men (Table 7). LEOs also reported that the most needed fit improvements were the waist and side areas for men, and chest and waist areas for women (Table 8). It is worth investigating the vest weight distribution and shoulder strap configuration issues to lessen officers’ pain. At the same time, armour-fit improvements at the chest, waist, side torso, and underarm areas, using the newly available LEO anthropometric data in armour design, are suggested.

5.3. Predicting armour fit and comfort and body pain - Does anthropometry matter?

Researchers and armour designers are likely to be interested in knowing the extent the body dimensions of a particular LEO can predict whether he or she will experience poot fit, discomfort, and body pain, and more specifically which dimensions are more important. Simple logistic regression provides a means to predict the probability of a body dimension on armour fit, armour discomfort, and body pain. Taking the probabilities of body dimensions on armour fit for women as an example, the most important dimensions would be chest circumference, chest depth, body mass index (BMI), stature, waist breadth (sitting), waist circumference, and chest breadth in the ranking order (Figure 6). Sitting height, weight (kg), waist front length (sitting), and front lateral length (standing) are not good predictors (Figure 6). For instance, the likelihood for a woman with a chest circumference of 800 mm is expected to have 0.78 probability to report a good fit of her armour while at 0.22 of probability to report a poor fit, when using the armour in the current marketplace (see the first plot in Figure 6). On the other hand, the likelihood for a woman with a chest circumference of 1300 mm is expected to have 0.31 probability to report a good fit of her armour while at 0.69 of probability to report a poor fit.

The predictabilities of these body dimensions correspond to their p-values of significance (Table 15). The results coincide with the body dimension difference between two body armour fit groups (poor fit vs. good fit) of women using the mean comparisons outlined in the Results section (Table 9). Similarly, the probabilities of body dimensions on armour discomfort and body pain for women match with the body dimension differences between two body armour comfort groups (discomfort vs. comfort; Table 11) and body pain groups (body pain vs. no symptom; Table 13). The simple logistic regression outcomes for men also agree with information in Tables 8, 10, and 12, confirming that anthropometry matters (Table 15).

5.4. Practical implications

This study identified eight important body dimensions associated with armour fit for a follow-up multivariate analysis to establish a sizing plan of armour for each gender group. Body armour sizing is a multivariate sorting problem. Of the many multivariate statistical analysis techniques available, cluster analysis is a top choice to the sorting problem. This approach places individuals into groups so that the individuals in any group are closer to each other than to individuals in other groups. Conventionally, body dimensions relevant to torso configurations are subjectively included in the analysis (Hsiao et al. 2015). This study scientifically ascertained the important body dimensions associated with armour fit. These dimensions will serve as the ‘drivers’ for more effectual cluster analyses to establish an optimal sizing system.

It is worth noting that waist-front length was not identified as a sensible dimension affecting the perceived armour fit, armour comfort, and body pain for female officers. There are three possible implications. First, Waist-Front Length measurement is a straight-line measurement and thus does not necessarily reflect the contour of chest of female officers. Second, while Waist-Front Length measurement does not play a significant role in clustering applications, it is a dimension that defines the length of armour. It is likely that only one armour length is needed for each cluster of female officers, which will be explored in a follow-up paper. Third, law enforcement body armour originated from military armour. With the study results (see Section 5.1), we can reasonably believe that military personnel anthropometry data are still in use for the current LEO armour designs, reflecting the mismatch in width and circumference measures while less a problem in length measurement (i.e., waist front length) as the differences between military personnel and LEOs in body widths and circumferences are significant and the difference in waist front length between the two woman groups are insignificant (Hsiao et al. 2021). This leads to the need for a complete revamp of the LEO sizing systems in the marketplace (rather than focusing on developing armour fit predicting models using the current market sizing schemes), which was the genesis of the current paper to identify the most relevant body dimensions for a follow analysis to develop an LEO body armour sizing structure for better LEO protection and well-being.

Finally, as armour manufacturers are moving into the use of ‘sizing vests’ for armour fit assessment, the eight important dimensions for males and females can be used, along with the newly available 3-dimensional LEO torso scans, to develop a set of multivariate-based torso models for which the adjustment range of each sizing vest component can be quantitively defined. The process will in turn assist manufacturers to systematically improve LEO body armour fit.

5.5. Study limitations

The LEO sample in this study was based on the geographic density of racial/ethnic distributions from the 2010 U.S. Census by four census regions (U.S. Census Bureau 2012) and the best available LEO age distribution in 2016 from the U.S. Bureau of Labor Statistics (2018). The study took ten years to complete – from the planning stage to various administrative and scientific reviews (2011–2017) to data collection (2018–2020). The racial/ethnic, age, and gender distributions may have changed to some extent during the 10 years, which is a limitation of the data.

Low response rate and missing data are common problems with questionnaire surveys. Inexperience with a topic, question fatigue, and loss of interest are among the causes of the challenges. This stratified sampling survey integrated the questionnaire survey in an in-person anthropometry measurement section with 19.5% of missing data for armour fit rating, 15.7% for armour comfort rating, 8.7% for body pain areas, and 9.3% for armour fit improvement areas, which is considered a very successful survey as compared to the typical customer survey response rate of 33% (Lindemann 2021). We did not conduct a follow up analysis to interpret any missing data which is a limitation.

This study included the chest breadth, chest circumference, and chest depth measurements in the analyses but not under-bust and over-bust chest circumferences for female officers. Therefore, detail assessments of effect of bra size on perceived armour fit and comfort were not possible which is a limitation.

This study did not perform a physical assessment of armour fit of each officer as officers were typically fitted by armour manufacturers or their internal agency representatives for their armour. They were instructed to rate the armour they were using. Additional data pertaining to armour size used, style used, user wear habits, wear duration, and perceived mobility of current armour are all valuable parameters to further our knowledge on armour improvement. However, it was a balance act of depth of the study, width/scope of the entire project, cost and time requirements of the research venture for such a scale of project. Nevertheless, the study identified association of torso anthropometric characteristics of LEO with perceived ratings of fit, comfort, and pain in the use of body armour with the limitations in mind. The author encourages armour research, standard, and manufacturing entities continuing to explore the effect of these listed parameters on armour fit and sizing.

More importantly, body armour sizes in the marketplace ranged from 6 to 25 sizes and they are not consistent in any way. The study team decided not to collect information on armour manufacturer, model, and size in that the information will have no practical utility. Instead, officers were asked to rate the armour they used on the daily basis. Because their armour was fitted by armour manufacturers or their internal agency representatives, we assumed that they have used the best fit armour available to them. In this sense, the study explored the match/mismatch between the LEO anthropometry and existing LEO armour as a whole. The results revealed that perceived armour fit, comfort with armour, and armour-caused pain were associated with certain LEO body dimensions.

6. Conclusion

Six key points can be concluded from this study. First, the correlation among armour fit rating, armour comfort rating, armour-caused body pain was moderate. An improvement of armour fit would increase armour comfort and lessen body armour-caused body pain. Second, armour fit was associated with certain LEO body dimensions. Female LEOs who reported *armour poor fit* had a smaller mean of Stature and larger mean of six body dimensions than the *armour good fit* group, while male LEOs who reported *armour poor fit* had a larger mean of nine body dimensions than the *armour good fit* group. Third, chest breadth, chest circumference, chest depth, stature, waist breadth (sitting), waist circumference at omphalion, body weight, and body mass index were eight influential body dimensions for *body armour fit and comfort* assessment for female LEOs; while chest breadth, chest circumference, chest depth, waist breadth (sitting), waist circumference at omphalion, waist front length (sitting), body weight, and body mass index were identified as the eight dominant body dimensions for *body armour fit and comfort* evaluation for male LEOs. Fourth, to effectively establish a sensible body armour sizing system that accommodates current law enforcement officers, a series of multivariate-based cluster analyses of the eight influential body dimensions by gender is suggested and will be presented in a follow-up paper. Fifth, the eight dimensions can be used along with the newly available 3-dimensional LEO torso scans to develop a set of multivariate-based body models for which the adjustment range of each *sizing vest component* can be defined. Finally, before an armour sizing system is fully developed, armour manufacturers can consider exploring the three most needed armour fit improvement areas - chest configuration, waist/stomach area, and side sections, as well as armour weight distribution at the neck/shoulder area for improved armour design.

Acknowledgement

The author extends his gratefulness to the entire research team, including NIOSH staff, project collaborators, and LEO associations for their support to the project. The NIOSH staff and project collaborators included Joyce Zwiener, Mathew Hause, Richard Whisler, Bradley Newbraugh, Darlene Weaver, James Green, Mahmood Ronaghi, Tony McKenzie, Gene Hill, Tsui-Ying Kau, Vernon McDougall, Tiffany Brake, Bruce Bradtmiller, and Belva Rockwell. Five national LEO associations and 13 police departments or training centers (in Arizona, Colorado, Maryland, Massachusetts, Minnesota, North Carolina, Ohio, Oklahoma, Tennessee, Utah, Virginia, West Virginia, and Wisconsin) contributed to the study.

Funding

This study was a part the NIOSH National Law Enforcement Officer (LEO) Anthropometry Research project and was funded through the NIOSH National Occupational Research Agenda.

Disclosure statement

No potential conflict of interest was reported by the author(s). The findings and conclusions in this report are those of the author and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH), Centres for Disease Control and Prevention (CDC) or Texas A&M University System. Mention of any company or product does not constitute endorsement by NIOSH, CDC, or Texas A&M University. In addition, citations to websites external to NIOSH do not constitute NIOSH or Texas A&M University endorsement of the sponsoring organisations or their programs or products. Furthermore, NIOSH and Texas A&M University are not responsible for the content of these websites. All web addresses referenced in this document were accessible as of the publication date.

References

ASTM (American Society for Testing and Materials) International. 2020. "Standard Practice for Body Armor Wearer Measurement and Fitting of Armor, E3003–20." Published August 2020. https://astm.org/e3003-20.html.

Burton KA, Tillotson KM, Symonds TL, Burke C, and Mathewson T. 1996. "Occupational Risk Factors for the First Onset and Subsequent Course of Low Back Trouble: A Study of Serving Police Officers." Spine 21 (22): 2612–2620. https://journals.lww.com/spinejournal/toc/1996/11150. doi:10.1097/00007632-199611150-00011. [PubMed: 8961449]

Choi HJ, Garlie T, Mitchell KB, and Desimone L. 2018. "Effects of Body Armor Fit on Warfighter Mobility as Measured by Range of Motion (ROM)." In Advances in Physical Ergonomics & Human Factors. AHFE 2018. Advances in Intelligent Systems and Computing, edited by Goonetilleke R and Karwowski W, vol. 789. Cham: Springer. doi:10.1007/978-3-319-94484-5_2.

Coltman CE, Brisbine BR, Molloy RH, Ball NB, Spratford WA, and Steele JR. 2021. "Identifying Problems That Female Soldiers Experience with Current-Issue Body Armour." Applied Ergonomics 94: 103384. doi:10.1016/j.apergo.2021.103384. [PubMed: 33690018]

Coltman CE, Brisbine BR, Molloy RH, and Steele JR. 2022. "Effect of Torso and Breast Characteristics on the Perceived Fit of Body Armour Systems among Female Soldiers: Implications for Body Armour Sizing and Design." Frontier in Sports and Active Living 4: 821210. doi:10.3389/fspor.2022.821210/full.

Cordner G, and Cordner A. 2011. "Stuck on a Plateau? Obstacles to Recruitment, Selection, and Retention of Women Police." Police Quarterly 14 (3): 207–226. doi:10.1177/1098611111413990.

Defense Centers for Public Health – Aberdeen (DCPH-A). 2020. "Anthropometric Database: ANSURII Database Female and ANSURII Database Male." https://phc.amedd.army.mil/topics/workplacehealth/ergo/Pages/Anthropometric-Database.aspx.

de Korte EM, Huysmans MA, de Jong AM, van de Ven JGM, and Ruijsendaal M. 2012. "Effects of Four Types of Non-Obtrusive Feedback on Computer Behaviour, Task Performance and Comfort." Applied Ergonomics 43 (2): 344–353. doi:10.1016/j.apergo.2011.06.010. [PubMed: 21726853]

De Looze MP, Kuijt-Evers LFM, and Van Dieën JH. 2003. "Sitting Comfort and Discomfort and the Relationships with Objective Measures." Ergonomics 46 (10): 985–997. doi:10.1080/0014013031000121977. [PubMed: 12850935]

Federal Bureau of Investigation (FBI). 2022a. "Crime Data: Law Enforcement Officers Killed in the Line of Duty Statistics for 2021." Bulletin Highlights. https://leb.fbi.gov/bulletin-highlights/additional-highlights/crime-data-law-enforcement-officers-killed-in-the-line-of-duty-statistics-for-2021.

Federal Bureau of Investigation (FBI). 2022b. "Law Enforcement Officers Killed and Assaulted." Uniform Crime Reports. https://ucr.fbi.gov/leoka/2019/topic-pages/tables/table-80.xls.

Gordon C, Corner B, and Brantley JD. 1997. "Defining Extreme Sizes and Shapes for Body Armor and Load-Bearing Systems Design: Multivariate Analysis of U.S. Army Torso Dimensions." Army Natick Research Development and Engineering Center, MA. https://apps.dtic.mil/sti/pdfs/ADA324730.pdf.

Grant H, Kubu B, Taylor B, Roberts J, Collins M, and Woods DJ. 2012. "Body Armor Use, Care, and Performance in Real World Conditions: Findings from a National Survey." November 2012, Document No: 240222. https://www.ojp.gov/pdffiles1/nij/grants/240222.pdf.

Greene M 2019. "Body Armor: Protecting Our Nation's Officers from Ballistic Threats." NIJ Journal 280: 1–5. (ojp.gov). https://www.ojp.gov/pdffiles1/nij/252033.pdf.

Hotzman J, Gordon CC, Bradtmiller B, Corner BD, Mucher M, Kristensen S, Paquette S, and Blackwell C. 2011. Measurer's Handbook: US Army and Marine Corps Anthropometric Surveys, 2010–2011 (TR-11–017). Natick, MA: U.S. Army Natick Soldier Research, Development, and Engineering Center.

Herzberg F, Mausner B, and Snyderman BB. 1959. The Motivation to Work. Somerset, NJ: Transaction Publishers.

Hsiao H 2013. "Anthropometric Procedures for Protective Equipment Sizing and Design." Human Factors 55 (1): 6–35. doi:10.1177/0018720812465640. [PubMed: 23516791]

Hsiao H 2023. "Assessment of Challenges in Patrol Vehicles and with Equipment Among Law Enforcement Officers." Applied Ergonomics 108: 103946. doi:10.1016/j.apergo.2022.103946. [PubMed: 36455489]

Hsiao H, Whisler R, Weaver D, Hause M, Newbraugh B, Zwiener J, Ronaghi M, Bradtmiller B, Rockwell B, McDougall V, and Brake T. 2021. "Encumbered and Traditional Anthropometry of Law Enforcement Officers for Vehicle Workspace and Protective Equipment Design." Human Factors: The Journal of the Human Factors and Ergonomics Society : 001872082110643. doi:10.1177/00187208211064371.

Hsiao H, Whitestone J, Kau TY, and Hildreth B. 2015. "Firefighter Hand Anthropometry and Structural Glove Sizing: A New Perspective." Human Factors 57 (8): 1359–1377. doi:10.1177/0018720815594933. [PubMed: 26169309]

Martin J, Sabeh R, Driver L, Lowe T, Hintze R, and Peters P. 1975. "Anthropometry of Law Enforcement Officers." In Law Enforcement Standards Laboratory, National Bureau of Standards (available as Technical Document 442). San Diego: Naval Electronics Laboratory Center.

National Institute of Law Enforcement and Criminal Justice. 1972. "NILECJ Standard on the Ballistic Resistance of Police Body Armor." U.S. Department of Justice, March 1972, https://www.ncjrs.gov/pdffiles1/Digitization/7037NCJRS.pdf.

National Institute of Justice (NIJ). 2008. National Institute of Justice 0101.06 Standard: Ballistic Resistance of Body Armor (NCJ 223054). Washington, DC: Department of Justice. https://www.nist.gov/system/files/documents/oles/ballistic.pdf.

National Institute of Justice (NIJ). 2014. National Institute of Justice Guide Body Armor: Selection and Application Guide 0101.06 to Ballistic-Resistant Body Armor (NCJ 247281). Washington, DC: Department of Justice. https://www.ojp.gov/pdffiles1/nij/247281.pdf.

LaTourrette T 2010. "The Life-Saving Effectiveness of Body Armor for Police Officers." Journal of Occupational and Environmental Hygiene 7 (10): 557–562. doi:10.1080/15459624.2010.489798. [PubMed: 20635298]

Lindemann N 2021. "What's the average survey response rate?" https://pointerpro.com/blog/average-survey-response-rate/ (Retrieved November 7, 2022).

Noro K, Naruse T, Lueder R, Nao N, and Kozawa M. 2012. "Application of Zen Sitting Principles to Microscopic Surgery Seating." Applied Ergonomics 43 (2): 308–319. doi:10.1016/j.apergo.2011.06.006. [PubMed: 21798514]

Niemczyk SE, Arnold L, and Wang L. 2020. "Incompatible Functions: Problems of Protection and Comfort Identified by Female Police Officers Required to Wear Ballistic Vests over Bras." International Journal of Fashion Design, Technology and Education 13 (2): 165–172. 10.1080/17543266.2020.1758800.

National Institute of Justice. 2012. "Survey of Officers on the Use and Care of Body Armor." nij.ojp.gov. https://nij.ojp.gov/topics/articles/survey-officers-use-and-care-body-armor.

Robinson C, and Horlick J. 2018. "Reducing Law Enforcement Officer Vulnerability by Closing the Gap in Body Armor Coverage and Fit." Proceedings of the Personal Armour Systems Symposium 2018, Washington, DC (and personal communication).

Schram B, Orr R, Hinton B, Pope R, and Norris G. 2019. "The Effects of Body Armor on the Power Development and Agility of Police Officers." Ergonomics 62 (10): 1349–1356. doi:10.1080/00140139.2019.1648878. [PubMed: 31343395]

Tavares JMA, Rodacki ALF, Hoflinger F, dos Santos Cabral A, Paulo AC, and Rodacki CLN. 2020. "Physical Performance, Anthropometrics and Functional Characteristics Influence the Intensity of Nonspecific Chronic Low Back Pain in Military Police Officers." International Journal of Environmental Research and Public Health 17 (17): 6434. doi:10.3390/ijerph17176434. [PubMed: 32899413]

Tiesman HM, Swedler DI, Konda S, and Pollack KM. 2013. "Fatal Occupational Injuries among U.S. Law Enforcement Officers: A Comparison of National Surveillance Systems." American Journal of Industrial Medicine 56 (6): 693–700. doi:10.1002/ajim.22182. [PubMed: 23532837]

U.S. Bureau of Labor Statistics. 2016. "Nonfatal Occupational Injuries and Illnesses Requiring Days Away from Work, 2015." https://www.bls.gov/news.release/pdf/osh2.pdf.

U.S. Bureau of Labor Statistics. 2018. "Household Data Annual Averages 11b. Employed Persons by Detailed Occupation and Age, 2016." https://www.bls.gov/cps/aa2016/cpsaat11b.pdf.

U.S. Bureau of Labor Statistics. 2020. "Household Data Annual Averages 11. Employed Persons by Detailed Occupation, Sex, Race, and Hispanic or Latino Ethnicity, 2019." https://www.bls.gov/cps/aa2019/cpsaat11.pdf.

U.S. Census Bureau. 2012. "Employed Civilians by Occupation, Sex, Race, and Hispanic Origin: 2010. Labor Force, Employment, and Earnings." Statistical Abstract of the United States 2012, 394. https://www2.census.gov/library/publications/2011/compendia/statab/131ed/2012-statab.pdf.

Vink P, and Hallbeck S. 2012. "Editorial: Comfort and Discomfort Studies Demonstrate the Need for a New Model." Applied Ergonomics 43 (2): 271–276. doi:10.1016/j.apergo.2011.06.001. [PubMed: 21724175]

Zhang L, Helander M, and Drury C. 1996. "Identifying Factors of Comfort and Discomfort." Human Factors 38 (3): 377–389. doi:10.1518/001872096778701962.

Figure 1.
Ballistic- and stab-resistant body armour provides coverage and protection for the vital organs, which safeguards LEOs against various kinds of threats (a). It consists of a front 'panel' overlapping the back 'panel' and is held in place on the wearer's torso by a carrier to protect the torso (b). A panel includes the ballistic materials and an enclosure that covers the materials, which fits in the carrier (c) (Picture credits: TurboSquid.com and National Institute of Justice (NIJ)) 2014).

Figure 2.

Sizing vests with adjustments in front width, front length, back width, and back length are being used to help officers in determining adequate armour sizes (side view – standing, front view – seated, and back view – standing) (Credit: drawings based on figures on the Armour Express Inc. web page).

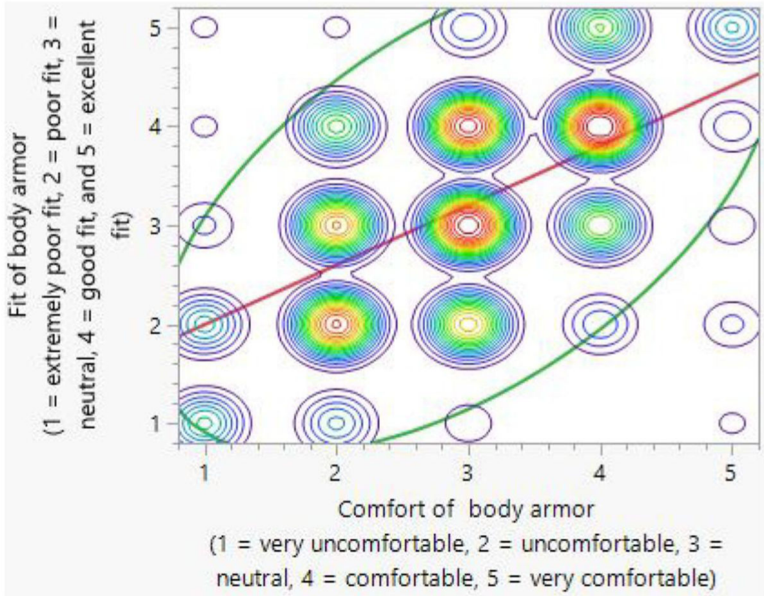


Figure 3.

A moderate positive correlation was found ($r = 0.56$) between armour fit and armour comfort. The colour theme shows nonparametric density of data with a fit line and a density ellipse of 0.95.

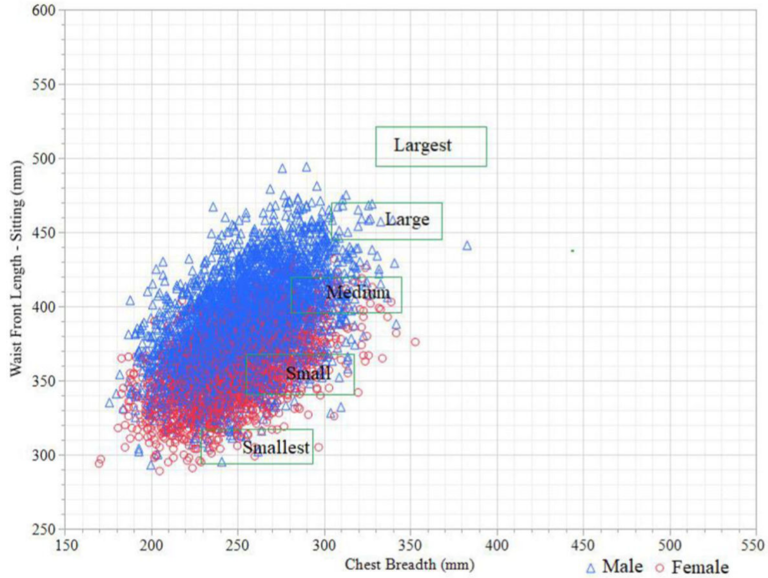


Figure 4.
U.S. army soldier waist-front length (sitting) and chest breadth distribution (*N*=6068) against the dimensions/sizes of armour ballistic test panels (the five rectangles) specified in the NIJ Standard – 0101.06.

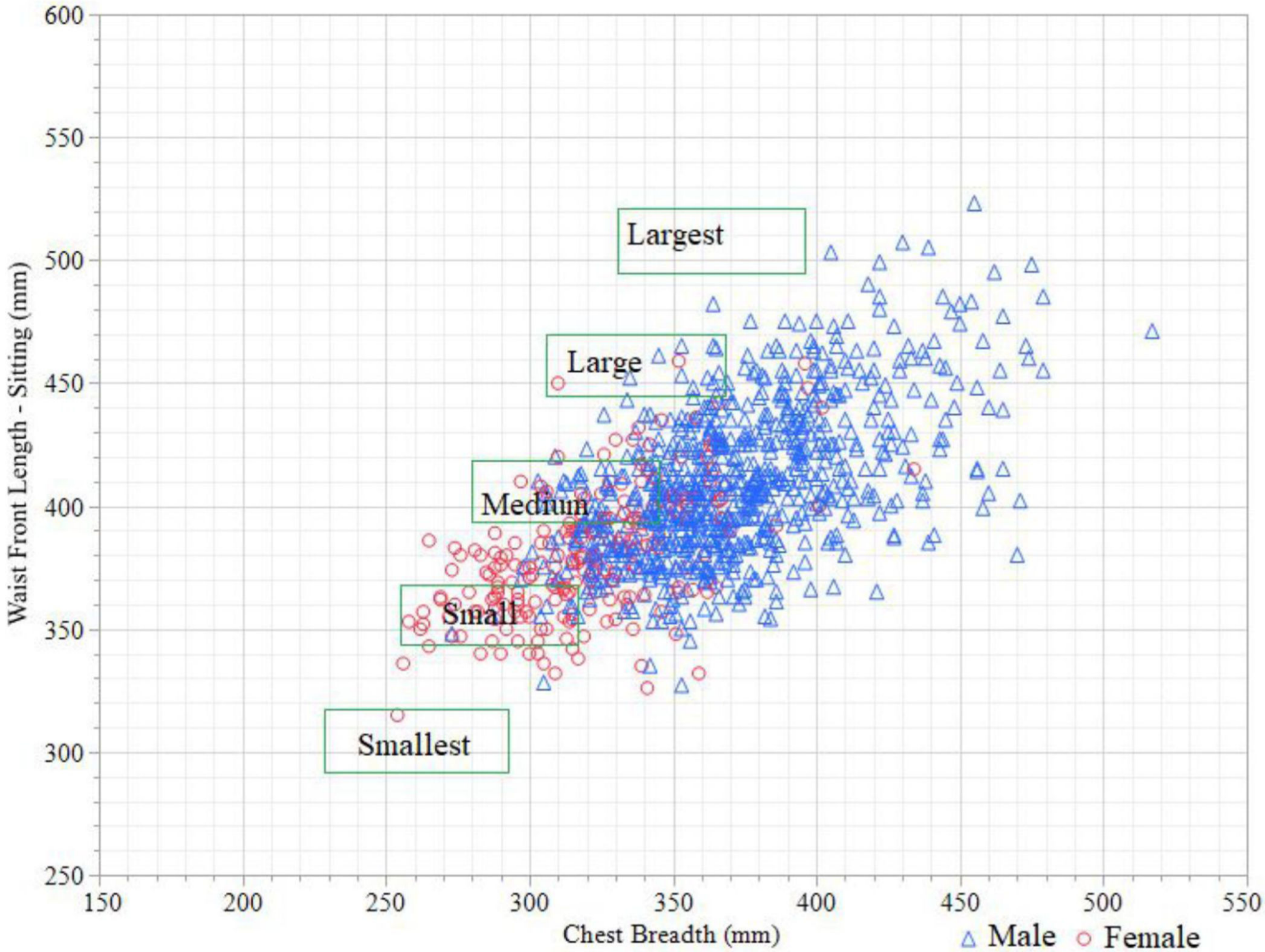


Figure 5.

LEO waist-front length (sitting) and chest breadth distribution (N=974) against the dimensions/sizes of armour ballistic test panels (the five rectangles) specified in the NIJ Standard – 0101.06.

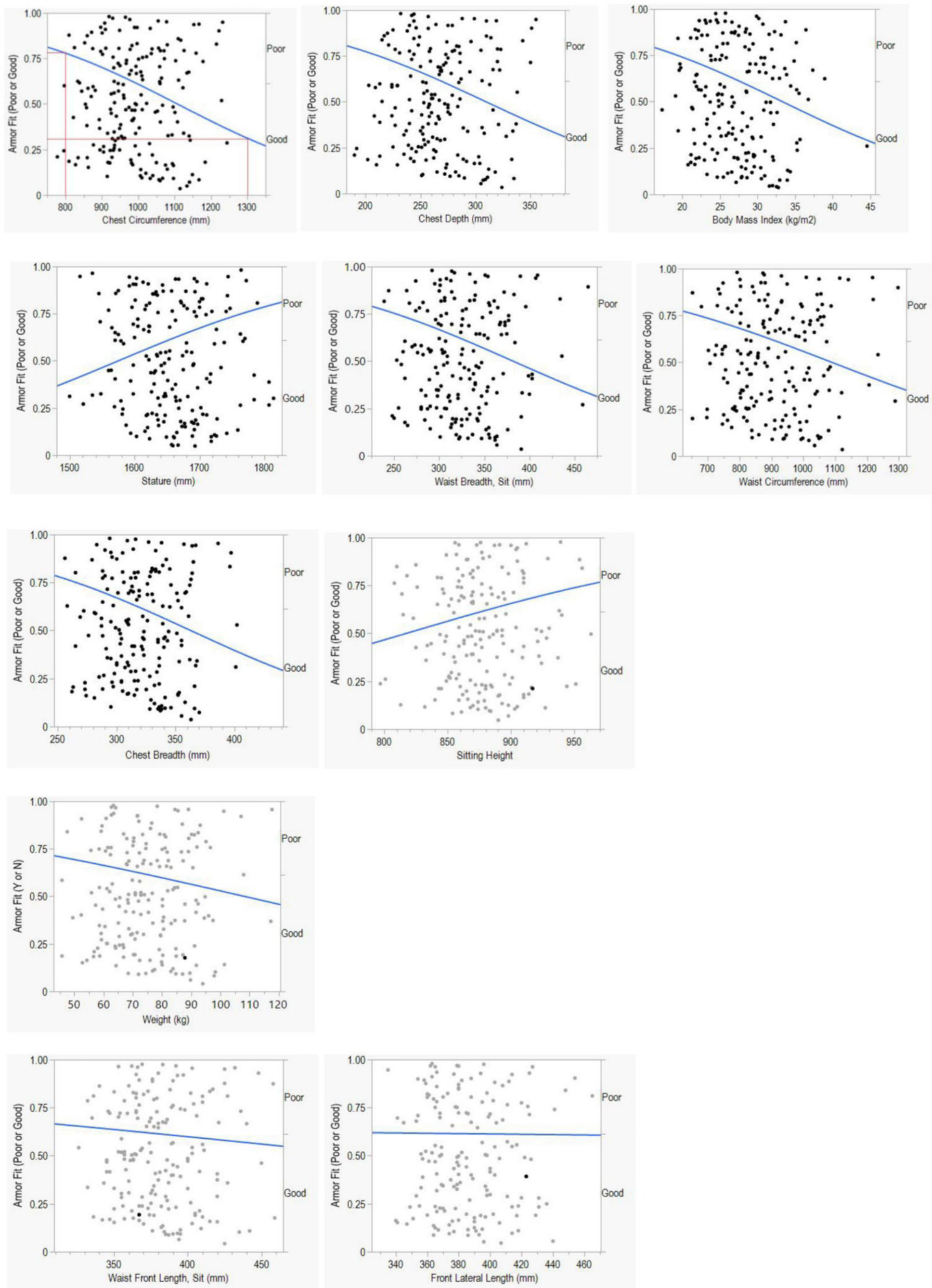


Figure 6.

The probability of a body dimension of women in predicting armour fit through simple logistic regression. Chest circumference, chest depth, body mass index (BMI), stature, waist breadth (sitting), waist circumference, and chest breadth are important dimensions in predicting armour fit in the ranking order (in dark colour). Sitting height, weight (kg), waist front length (sitting), and front lateral length (standing) are not good predictors (in gray colour).

Table 1.

Participants by racial/ethnic group, sex, and age (Hsiao et al. 2021).

Race/ethnicity Sex	White N = 685						Black N = 124		Hispanic/Other N = 165		
	Males			Females			Males	Females	Males	Females	
Age	**18–34**	**35–44**	**45–54**	**18–34**	**35–44**	**45–54**	**24–57**	**24–63**	**23–57**	**23–56**	**Total**
Stratified samples	188	183	172	52	62	28	93	31	120	45	974

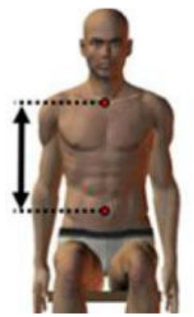
Table 2.

Body dimensions relevant to LEO armour configuration (adapted from Hsiao et al. 2021 and Hotzman et al. 2011).

Item	Variable		Description
1	Chest breadth		The maximum horizontal breadth of the chest at the level of the chest point anterior landmark.
2	Chest circumference (chest/bust girth)		The maximum circumference of the chest at the fullest part of the breast.

Item	Variable		Description
3	Chest depth		The horizontal distance between the right chest point anterior landmark and the back at the same level.
4	Sitting height		The vertical distance between a sitting surface and the top of the head.

Item	Variable		Description
5	Stature		The vertical distance from a standing surface to the top of the head.
6	Waist breadth, sitting		The horizontal breadth of the waist at the level of omphalion.

Item	Variable		Description
7	Waist circumference at omphalion		The horizontal circumference of the waist at the level of omphalion encompassing the waist (omphalion) landmarks.
8	Waist front length (WFL), sitting		The surface distance between the suprasternale landmark at the lowest point of the notch at the top of the breastbone and omphalion while seated.

Item	Variable		Description
9	Weight (kg)		Participant stands on the platform of the scale with weight distributed evenly on both legs. Stand in front of the participant and take the weight of the participant to the nearest tenth of a kilogram.

Author Manuscript
Author Manuscript
Author Manuscript

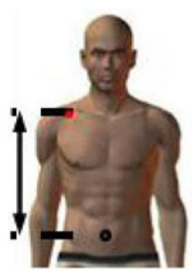
Item	Variable		Description
10	Body mass index (BMI)		BMI = Weight/Stature^2
11	Front lateral length, standing (similar to waist front length, standing)		The surface distance between the suprasternale landmark at the lowest point of the notch at the top of the breastbone and omphalion while standing.

Table 3.

Body dimensions relevant to LEO armour configuration and dimension differences between male and female officers (weight in kg; body mass index in no unit; others in mm).

	Males				Females				
Dimension	***N***	**Mean**	**Std dev**	**Std error**	***N***	**Mean**	**Std dev**	**Std error**	**Sig Diff[+] (*p*-value)**
Chest breadth	756	372	36	1.3	218	320	30	2.0	<.001
Chest circumference	756	1111	101	3.7	218	987	101	6.9	<.001
Chest depth	756	281	30	1.1	218	266	35	2.4	<.001
Sitting height	756	930	35	1.3	218	875	31	2.1	<.001
Stature	756	1778	71	2.6	217	1651	63	4.3	<.001
Waist breadth, sitting	756	359	40	1.5	218	325	41	2.8	<.001
Waist circumference at Om	756	1026	130	4.7	218	904	126	8.5	<.001
Waist-front length, sitting	756	409	31	1.1	217	380	26	1.8	<.001
Weight (kg)	756	95.5	17.5	0.6	218	74.3	13.6	0.9	<.001
Body mass index (BMI)[*]	756	30.2	4.8	0.2	217	27.3	4.6	0.3	<.001
Front lateral length, standing	699	420	30.5	1.2	200	384	24.8	1.8	<.001

[*] Body mass index (BMI) was derived from weight and stature.

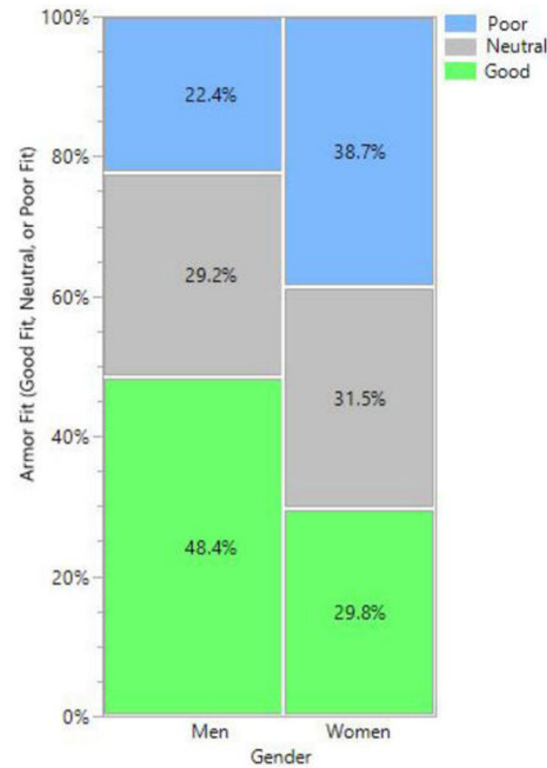
[+] Two-tail *t*-tests were used to determine the significant difference in torso dimensions between male and female LEOs. Adjusted significant level of $p = .05/11 = 0.0045$ was employed for the eleven-paired comparisons.

Table 4.

Ratings of body armour fit by gender of law enforcement officers.

Body armour fit		Total		Men		Women	
		N	%	*N*	%	*N*	%
Poor fit	Extreme poor fit (rating: 1)	36	4.6	23	3.8	13	7.2
	Poor fit (rating: 2)	169	21.6	112	18.6	57	31.5
Neutral	Neutral (rating: 3)	237	30.2	178	29.5	59	32.6
Good fit	Good fit (rating: 4)	282	35.9	241	40.0	41	22.6
	Excellent fit (rating: 5)	60	7.7	49	8.1	11	6.1
	Subtotal	784	100.0	603	100.0	181	100.0
	Missing	190		153		37	
	Total	974		756		218	

Body armour fit	Total		Men		Women	
	N	%	*N*	%	*N*	%



Author Manuscript

Author Manuscript

Author Manuscript

Table 5.

Law enforcement officers body armour comfort rating.

Body armour comfort		Total *N*	Total %	Men *N*	Men %	Women *N*	Women %
Uncomfortable	Very uncomfortable (rating: 1)	48	5.9	31	4.9	17	9.0
	Uncomfortable (rating: 2)	214	26.0	146	23.1	68	36.0
Neutral	Neutral (rating: 3)	315	38.4	250	39.6	65	34.4
Comfortable	Comfortable (rating: 4)	213	25.9	184	29.2	29	15.3
	Very comfortable (rating: 5)	31	3.8	21	3.2	10	5.3
	Subtotal	821	100	632	100	189	100
	Missing	153		124		29	
	Total	974		756		218	

	Total		Men		Women	
Body armour comfort	*N*	%	*N*	%	*N*	%

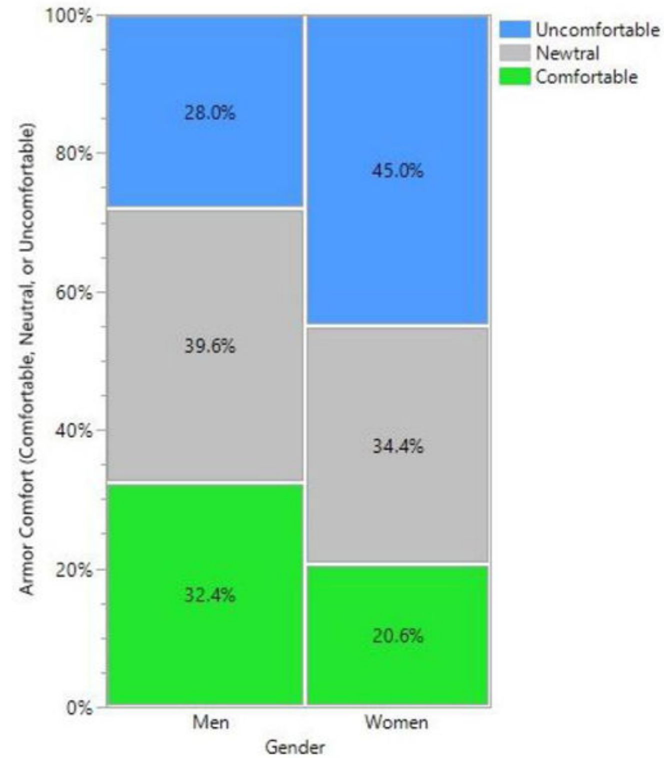


Table 6.

Body armours-caused LEO pain/discomfort in specific body areas.

	Total		Men		Women	
Pain/Discomfort	**N**	**%**	**N**	**%**	**N**	**%**
None	406	45.7	343	49.8	63	31.5
At least one body area	483	54.3	346	50.2	137	68.5
Total	889		689		200	
Pain/Discomfortable area						
Neck	225	25.3	163	23.7	62	31.0
Underarm	164	18.4	118	17.1	46	23.0
Chest	96	10.8	52	7.5	44	22.0
Waist	129	14.5	96	13.9	33	16.5
Hips	74	8.3	52	7.5	22	11.0
Other	50	5.6	37	5.4	13	6.5

Table 7.

Areas of body armour fit in need for improvement.

	Total		Men		Women	
Armour fit improvement	***N***	**%**	***N***	**%**	***N***	**%**
None	272	30.8	230	33.7	42	21.0
At least one body area	611	69.2	453	66.3	158	79.0
Total	883		683		200	
Missing	91		73		18	
Areas for armour improvement *						
Neck	60	9.8	43	6.3	17	8.5
Underarm	54	8.8	39	5.7	15	7.5
Chest	153	25.0	63	9.2	90	45.0
Waist/Stomach	132	21.5	102	14.9	30	15.0
Hips	36	5.9	28	4.1	8	4.0
Back	37	6.0	27	4.0	10	5.0
Front panel	16	2.6	9	1.3	7	3.5
Side	119	19.4	98	14.3	21	10.5
Velcro/Overlap	13	2.1	8	1.2	5	2.5
Weight	12	2.0	10	1.5	2	1.0
Flexible	25	4.1	22	3.2	3	1.5
Straps	17	2.8	13	1.9	4	2.0
Shoulders	60	9.8	46	6.7	14	7.0
Armour sizing	84	13.7	71	10.4	13	6.5
Breathable	9	1.5	9	1.3	0	0.0
Others	6	1.0	6	0.9	0	0.0

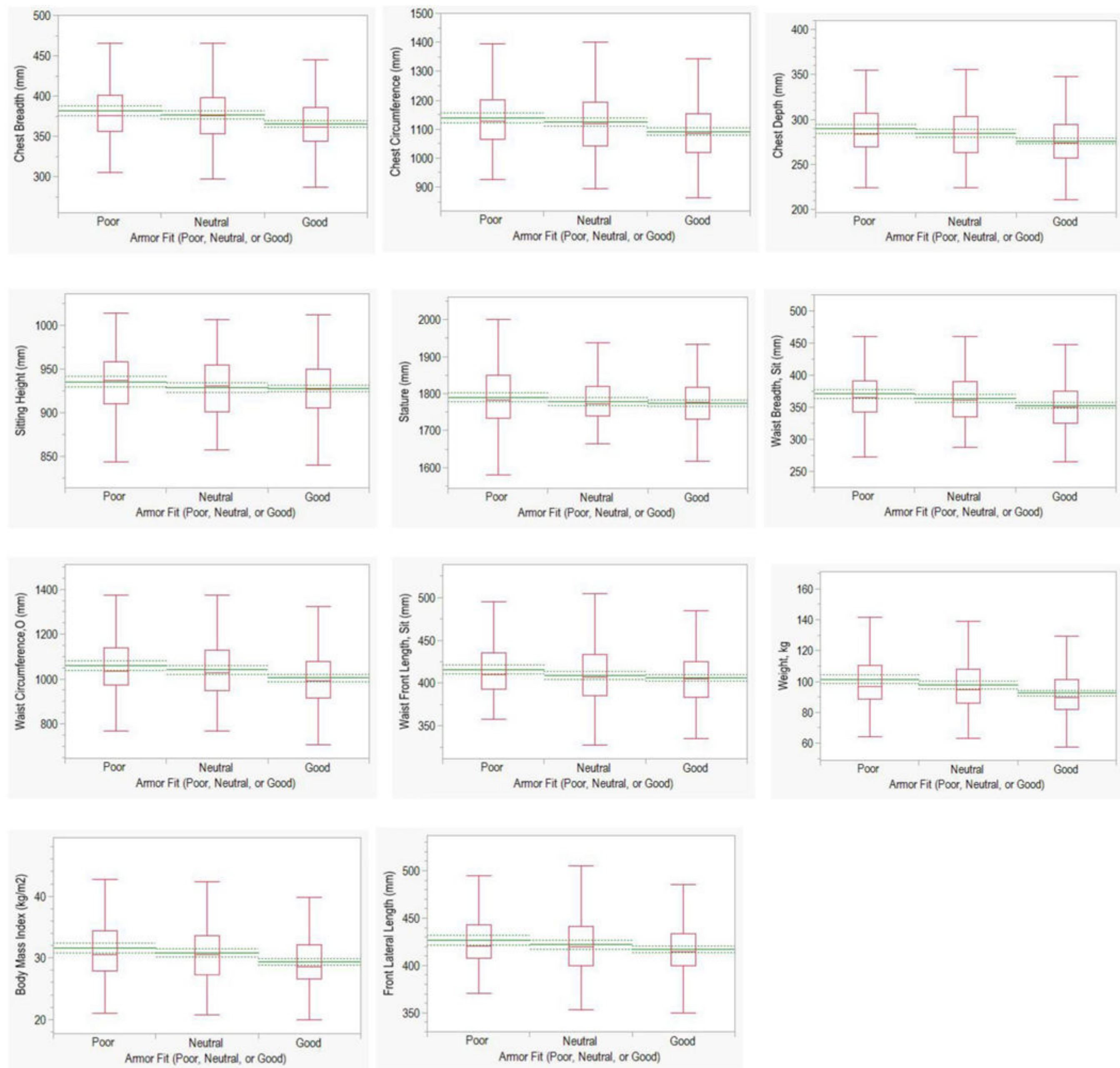
* The percentages do not total to 100%, as officers reported more than one armour components for fit improvement.

Table 8.

Body dimension differences among body armour fit groups using all-pairs Tukey–Kramer HSD comparisons with box plots for male officers (unit in kg for weight, kg/m^2 for BMI, all others in mm).

		Mean (male officers)			All pairs comparisons (*p*-value)*		
Item	**Variable (body dimension)**	**Poor fit (P)**	**Neutral (N)**	**Good Fit (G)**	**P-N**	**N-G**	**P-G**
1	Chest breadth/Back width	382	377	366	0.461	**0.0024**	**<.0001**
2	Chest circumference	1139	1124	1092	0.408	**0.0021**	**<.0001**
3	Chest depth	289	284	276	0.279	**0.0103**	**<.0001**
4	Sitting height	935	929	928	0.216	0.957	.091
5	Stature	1790	1779	1774	0.739	0.328	.064
6	Waist breadth, sitting	371	364	353	0.262	**0.011**	**<.0001**
7	Waist circumference at om	1061	1041	1004	0.380	**0.009**	**.0001**
8	Waist front length, sitting	416	409	406	0.556	0.143	**.0074**
9	Weight (kg)	101.4	97.7	92.4	0.141	**0.003**	**<.0001**
10	Body mass index (BMI)	31.6	30.8	29.4	0.328	**0.004**	**<.0001**
11	Front lateral length	427	422	417	0.371	0.242	**.009**

Item	Variable (body dimension)	Mean (male officers)			All pairs comparisons (*p*-value)*		
		Poor fit (P)	Neutral (N)	Good Fit (G)	P-N	N-G	P-G



P-N: significant level (in *p*-value) between poor fit and neutral groups.

N-G: significant level (in *p*-value) between neutral and good fit groups.

P-G: significant level (in *p*-value) between poor fit and good fit groups.

Bolded body dimensions: significant difference in means among body armour fit groups.

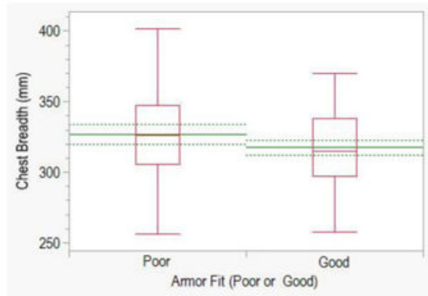
Boxplots: Body dimensions in means (solid green lines) and confidence intervals (CI) of means (dotted lines; 95% two-tail CI) by perceived armour fit rating. The boxplots show maximum, upper quartile, median, lower quartile, and minimum values of the body dimensions within each armour fit rating group.

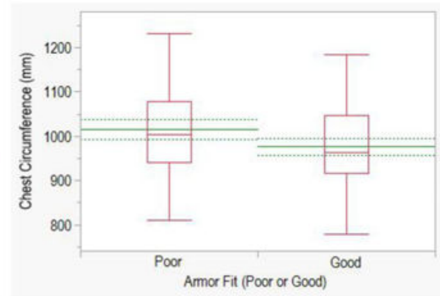
Table 9.

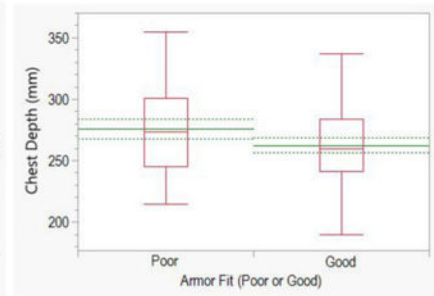
Body dimension differences between two body armour fit groups using mean comparisons along with box plots for women (unit in kg for weight, kg/m^2 for BMI, all others in mm).

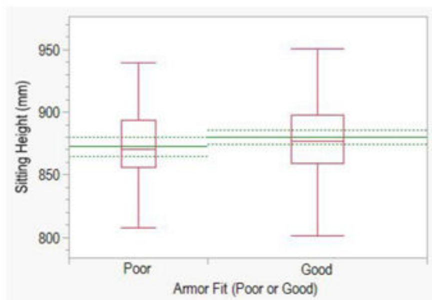
		Mean (women)		Comparison	
Item	**Variable (body dimensions)**	**Poor fit (P)**	**Neutral (N) + good fit (G)**	***t*-Value**	**P-N&G (*p*-value)***
1	Chest breadth/Back width	327	317	**2.16**	**.0318**
2	Chest circumference	1016	976	**2.61**	**.0101**
3	Chest depth	275	262	**2.48**	**.0142**
4	Sitting height	872	880	1.56	.1200
5	Stature	1642	1663	**2.27**	**.0247**
6	Waist breadth, sitting	335	321	**2.21**	**.0288**
7	Waist circumference at Om	936	894	**2.12**	**.0360**
8	Waist front length, sitting	383	381	0.53	.5942
9	Weight (kg)	76.8	74.3	1.22	.2254
10	Body mass index (BMI)	28.4	26.8	**2.32**	**.0218**
11	Front lateral length	386	386	0.05	.9575

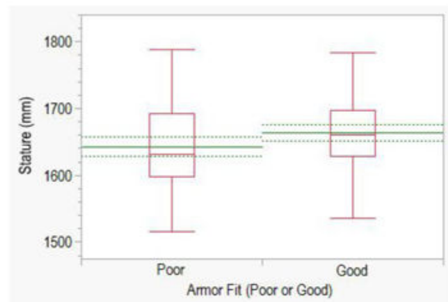
Item	Variable (body dimensions)	Mean (women)		Comparison	
		Poor fit (P)	Neutral (N) + good fit (G)	*t*-Value	P-N&G (*p*-value)*

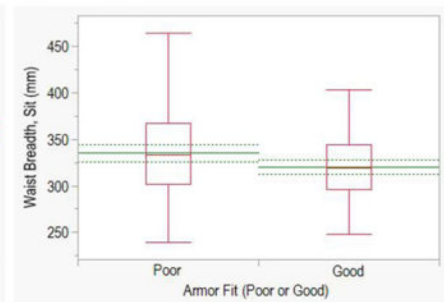


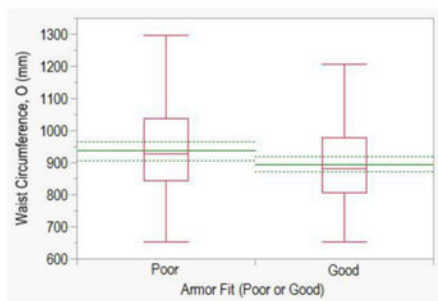


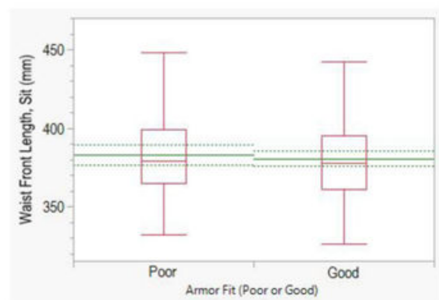


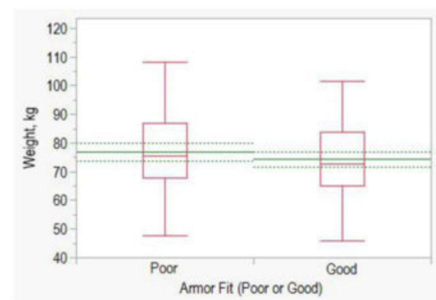


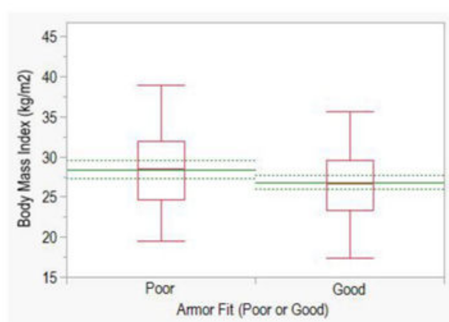


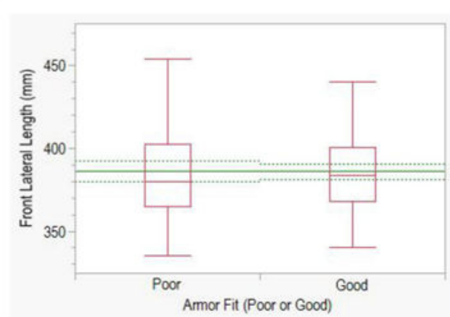












*P-N&G: significant level (in *p*-value) between poor fit and good fit (including neutral and good fit) groups.

Bolded body dimensions: significant difference in means between body armour fit groups.

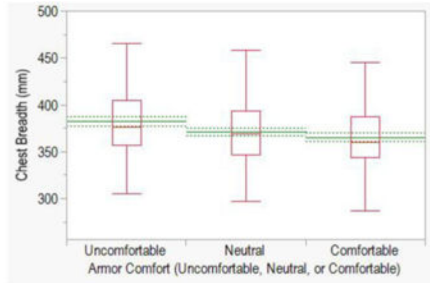
Boxplots: body dimensions in means (solid green lines) and confidence intervals (CI) of means (dotted lines; 95% two-tail CI) by perceived armour fit rating. The boxplots show maximum, upper quartile, median, lower quartile, and minimum values of the body dimensions within each armour fit rating group.

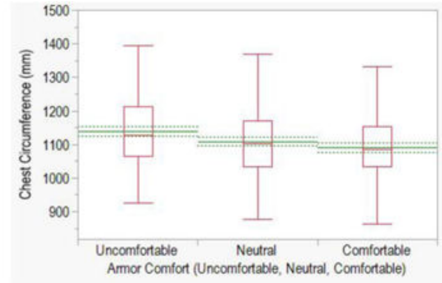
Table 10.

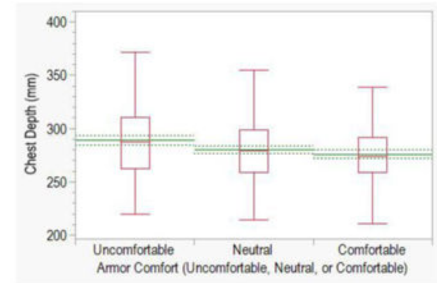
Body dimension differences among body armour comfort groups using all-pairs Tukey–Kramer HSD comparisons along with box plots for men (unit: kg for weight, kg/m^2 for BMI, all others mm).

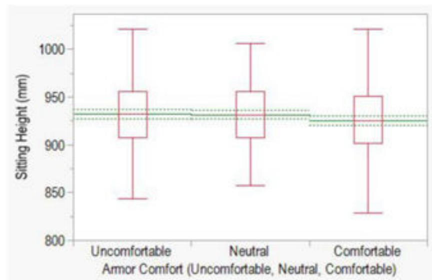
		Mean (men)			All pairs comparisons (*p*-value)		
Item	**Variable (body dimensions)**	**Uncomfortable (U)**	**Neutral (N)**	**Comfortable (C)**	**U-N**	**N-C**	**U-C**
1	Chest breadth	383	371	365	**0.003**	0.159	**<.0001**
2	Chest circumference	1139	1109	1091	**0.006**	0.167	**<.0001**
3	Chest depth	289	280	276	**0.009**	0.280	**<.0001**
4	Sitting height	932	931	925	0.947	0.179	.131
5	Stature	1784	1785	1768	0.995	**0.025**	.056
6	Waist breadth, sitting	369	358	355	**0.011**	0.644	**<.0001**
7	Waist circumference at om	1058	1021	1010	**0.011**	0.645	**.0010**
8	Waist front length, sitting	414	410	406	0.366	0.408	**.0367**
9	Weight (kg)	100.6	96.0	92.3	0.**022**	0.065	**<.0001**
10	Body mass index (BMI)	31.5	30.1	29.5	**0.007**	0.425	**.0002**
11	Front lateral length	427	421	416	0.172	0.279	**.0054**

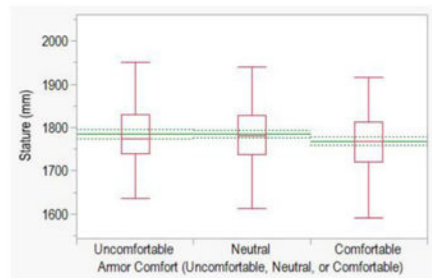
Item	Variable (body dimensions)	Mean (men)			All pairs comparisons (*p*-value)		
		Uncomfortable (U)	Neutral (N)	Comfortable (C)	U-N	N-C	U-C

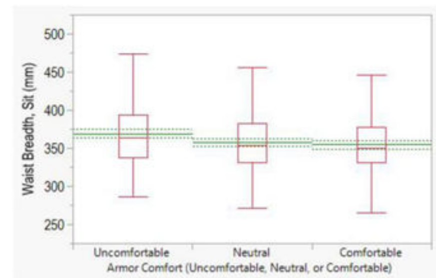


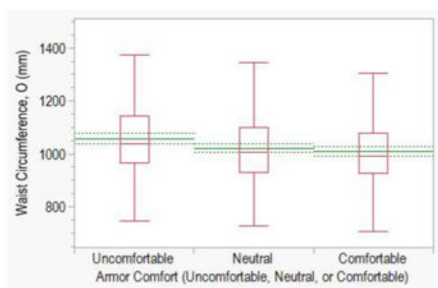


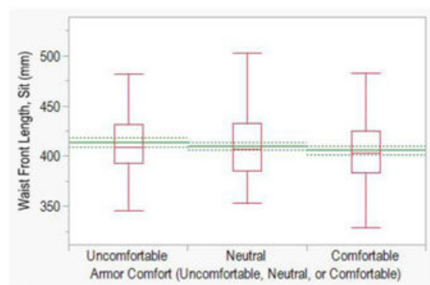


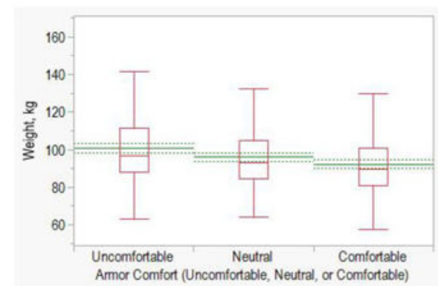


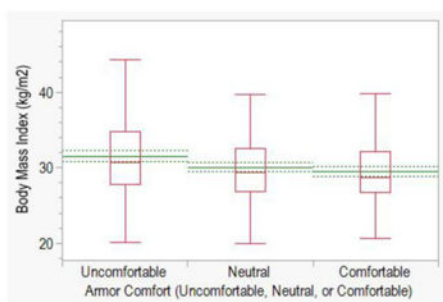


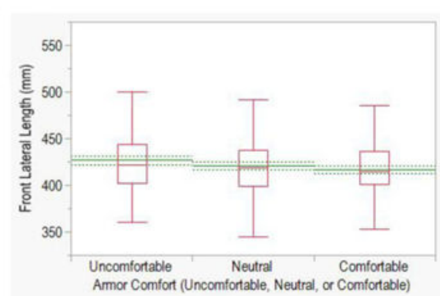












U-N: significant level (in *p*-value) between uncomfortable and neutral groups.

N-C: significant level (in *p*-value) between neutral and comfortable groups.

U-C: significant level (in *p*-value) between uncomfortable and comfortable groups.

Bolded body dimensions: significant difference in means among body armour comfort groups.

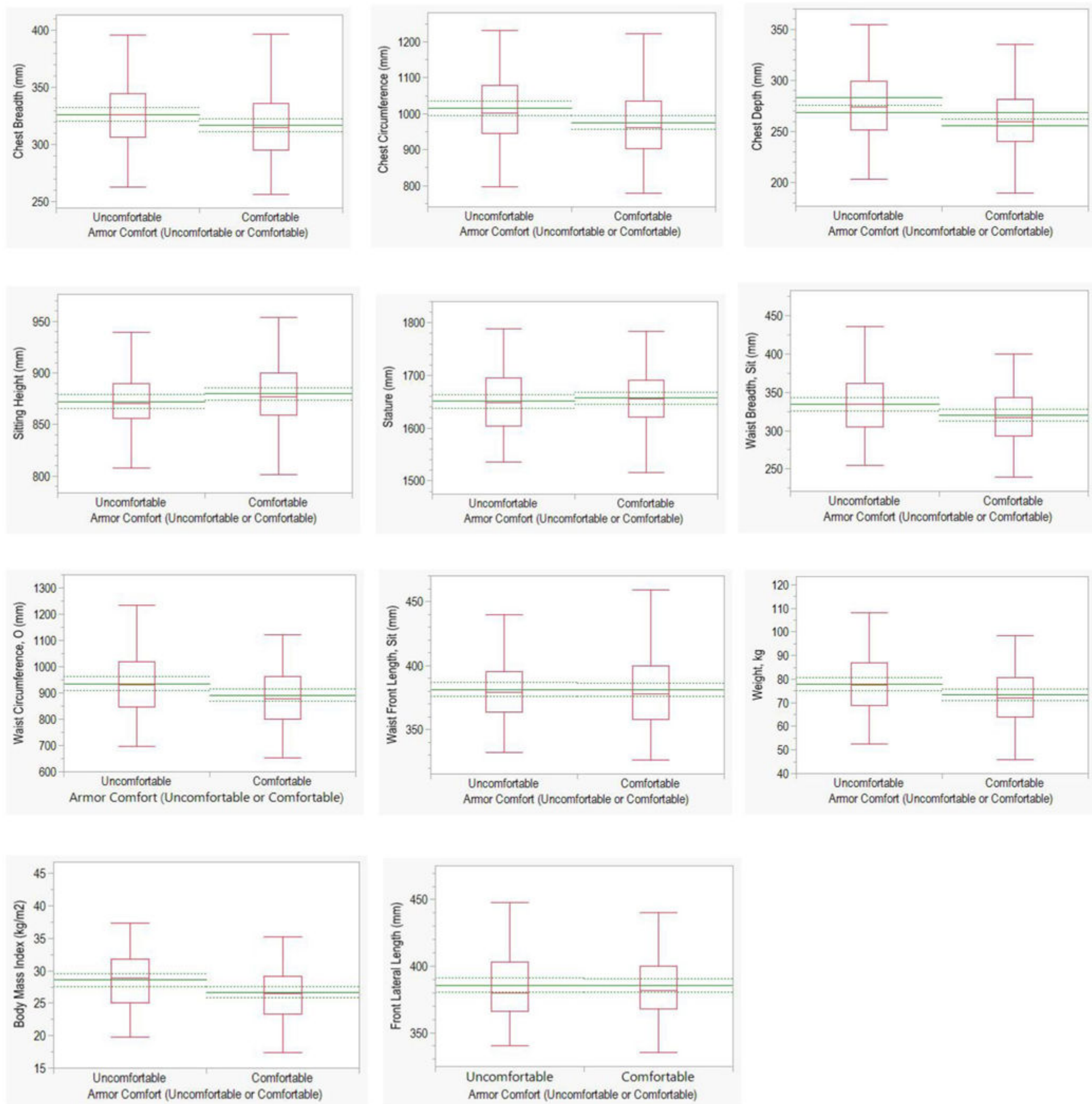
Boxplots: body dimensions in means (solid green lines) and confidence intervals (CI) of means (dotted lines; 95% two-tail CI) by perceived armour comfort rating. The boxplots show maximum, upper quartile, median, lower quartile, and minimum values of the body dimensions within each armour comfort rating group.

Table 11.

Body dimension differences between two *body armour comfort* groups using mean comparisons for *female* officers (unit in kg for weight, no unit for BMI, all others in mm).

		Mean (women)		Comparison	
Item	**Variable (body dimensions)**	**Uncomfortable (U)**	**Neutral (N) + comfortable (C)**	***t*-Value**	**U-N&C (*p*-value)***
1	Chest breadth/Back width	326	317	**2.22**	**.0273**
2	Chest circumference	1015	976	**2.82**	**.0053**
3	Chest depth	276	262	**2.75**	**.0064**
4	Sitting height	872	880	1.70	.0900
5	Stature	1651	1657	0.68	.4986
6	Waist breadth, sitting	335	320	**2.54**	**.0120**
7	Waist circumference at om	936	891	**2.49**	**.0137**
8	Waist front length, sitting	381	381	0.03	.9766
9	Weight (kg)	77.8	73.4	**2.34**	**.0205**
10	Body mass index (BMI)	28.6	26.7	**2.93**	**.0038**
11	Front lateral length	386	385	0.13	.8969

Item	Variable (body dimensions)	Mean (women)		Comparison	
		Uncomfortable (U)	Neutral (N) + comfortable (C)	*t*-Value	U-N&C (*p*-value)*



*P-N&G: significant level (in *p*-value) between poor fit and good fit (including neutral and good fit) groups.

Bolded body dimensions: significant difference in means between body armour comfort groups.

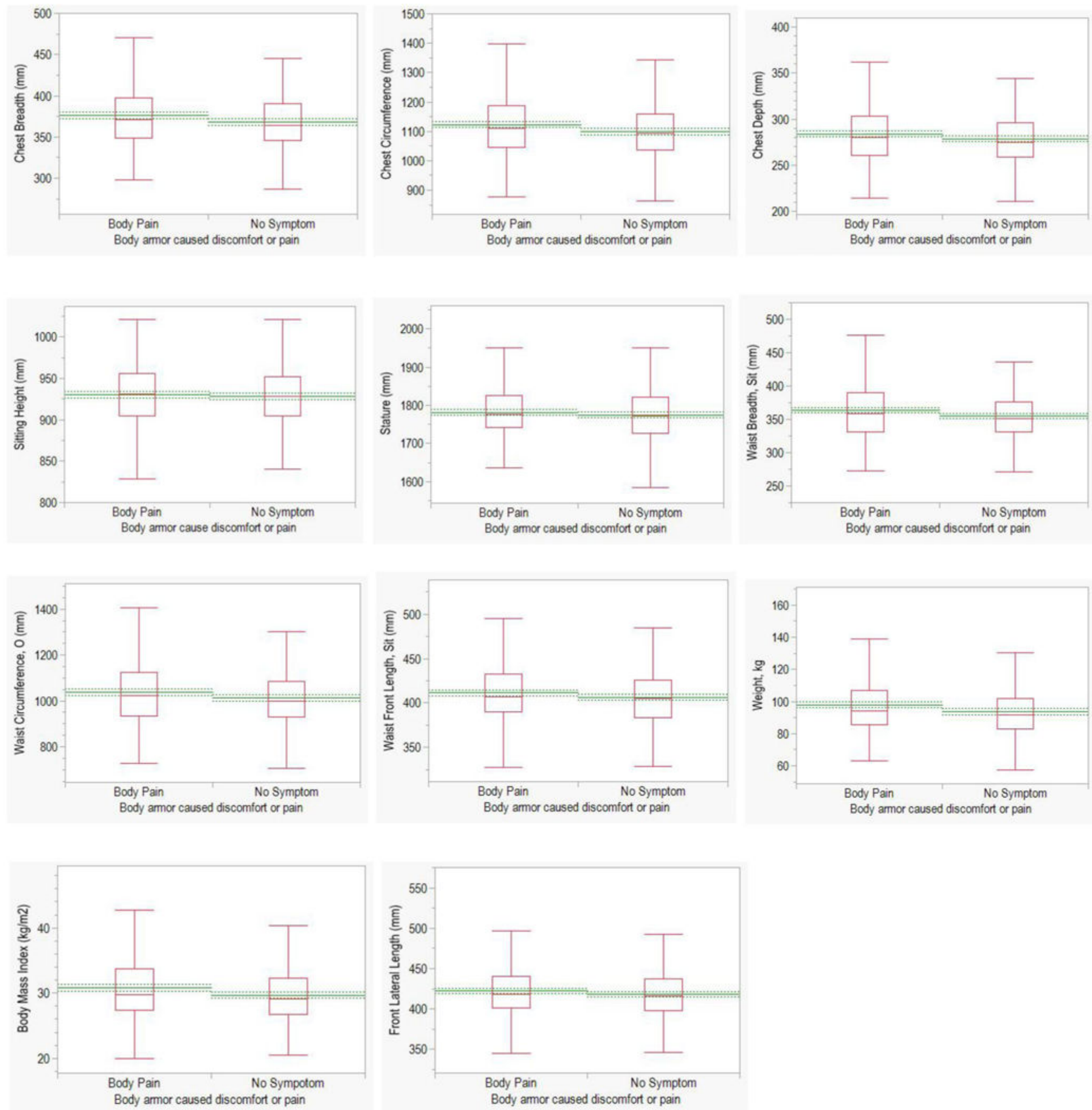
Boxplots: body dimensions in means (solid green lines) and confidence intervals (CI) of means (dotted lines; 95% two-tail CI) by perceived armour comfort rating. The boxplots show maximum, upper quartile, median, lower quartile, and minimum values of the body dimensions within each armour comfort rating group.

Table 12.

Association between body armour caused pain and body dimensions along with box plots among male officers (unit in kg for weight, kg/m^2 for BMI, all others in mm).

Item	Variable (body dimensions)	No symptom group	Body pain group	*t*	*p*-Value
1	Chest breadth/Back width	368	376	3.05	**.002**
2	Chest circumference	1099	1123	3.11	**.002**
3	Chest depth	279	284	2.41	**.016**
4	Sitting height	928	930	0.71	.476
5	Stature	1774	1781	1.33	.185
6	Waist breadth, sitting	355	364	2.85	**.005**
7	Waist circumference at Om	1013	1038	2.52	**.012**
8	Waist front length, sitting	406	411	2.29	**.023**
9	Weight (kg)	93.7	97.9	3.18	**.002**
10	Body mass index (BMI)	29.7	30.8	2.97	**.003**
11	Front lateral length	418	422	1.86	.064

Item	Variable (body dimensions)	No symptom group	Body pain group	*t*	*p*-Value



Bolded body dimensions: significant difference in means between body armour-caused pain groups.

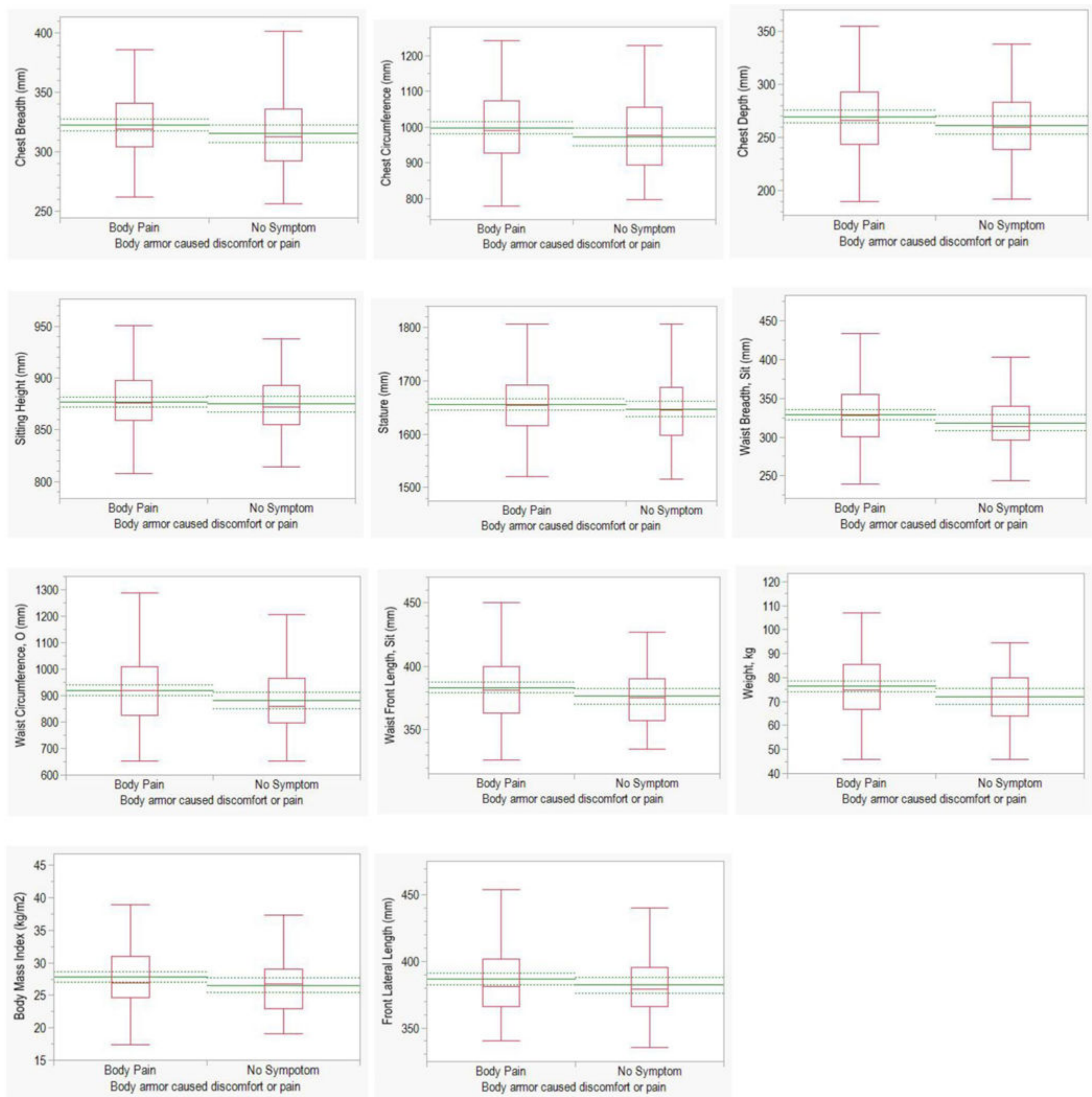
Boxplots: body dimensions in means (solid green lines) and confidence intervals (CI) of means (dotted lines; 95% two-tail CI) by perceived armour-caused pain rating. The boxplots show maximum, upper quartile, median, lower quartile, and minimum values of the body dimensions within each armour caused pain rating group.

Table 13.

Association between body armour caused pain and body dimensions along with box plots among female officers (unit in kg for weight, no unit for BMI, all others in mm).

Item	Variable (body dimensions)	No symptom group	Body pain group	*t*	*p*-Value
1	Chest breadth/Back width	315	323	1.65	.102
2	Chest circumference	972	998	1.72	.089
3	Chest depth	262	270	1.59	.115
4	Sitting height	875	877	0.43	.667
5	Stature	1647	1656	0.91	.366
6	Waist breadth, sitting	319	329	1.76	.082
7	**Waist circumference at om**	882	920	2.07	**.041**
8	Waist front length, sitting	376	383	1.88	.062
9	Weight (kg)	72.1	76.4	2.26	**.025**
10	Body mass index (BMI)	26.5	27.8	1.98	**.050**
11	Front lateral length	382	387	1.19	.237

Item	Variable (body dimensions)	No symptom group	Body pain group	*t*	*p*-Value



Bolded body dimensions: significant difference in means between body armour-caused pain groups.

Boxplots: body dimensions in means (solid green lines) and confidence intervals (CI) of means (dotted lines; 95% two-tail CI) by perceived armour-caused pain rating. The boxplots show maximum, upper quartile, median, lower quartile, and minimum values of the body dimensions within each armour caused pain rating group.

Table 14.

Summary of associated between body dimensions and body armour fit, perceived armour discomfort, and armour-caused pain.

		Women			Men		
Item	**Variable**	**Armour poor fit**	**Perceived discomfort**	**Armour-caused pain**	**Armour poor fit**	**perceived discomfort**	**Armour-caused pain**
1	Chest breadth	**X+**	**X+**		**X+**	**X+**	**X+**
2	Chest circumference	**X+**	**X+**		**X+**	**X+**	**X+**
3	Chest DEPTH	**X+**	**X+**		**X+**	**X+**	**X+**
4	Sitting Height						
5	Stature	**X−**					
6	Waist breadth, sitting	**X+**	**X+**		**X+**	**X+**	**X+**
7	Waist circumference at Om	**X+**	**X+**	**X+**	**X+**	**X+**	**X+**
8	Waist front length, sitting				**X+**	**X+**	**X+**
9	Weight (kg)		**X+**	**X+**	**X+**	**X+**	**X+**
10	Body mass index (BMI)	**X+**	**X+**		**X+**	**X+**	**X+**
11	Front lateral length, standing				X+	X+	

X+: The *armour poor fit*, *uncomfortable with armour*, and *armour-caused pain* groups had a larger mean of the body dimension than their *counterparts* (i.e., armour good fit, comfortable with armour, and no armour-caused pain groups).

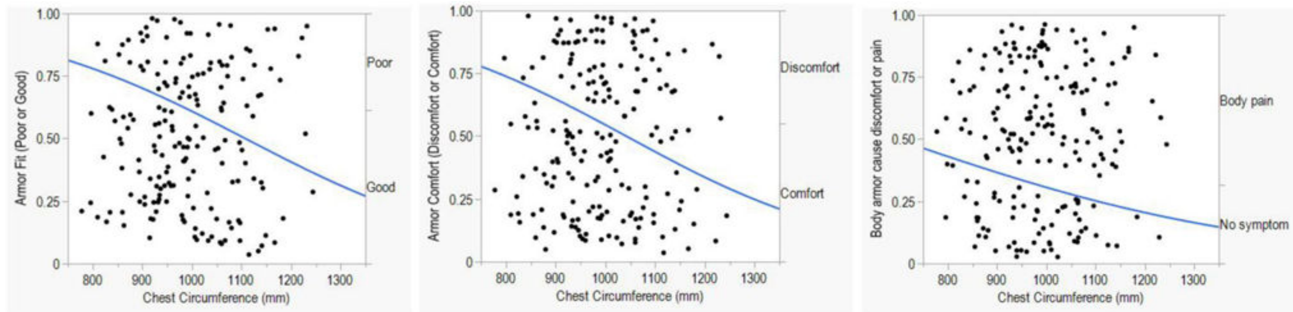
X−: The *armour poor fit* group had a smaller mean of the body dimension than the *armour good fit* group.

Table 15.

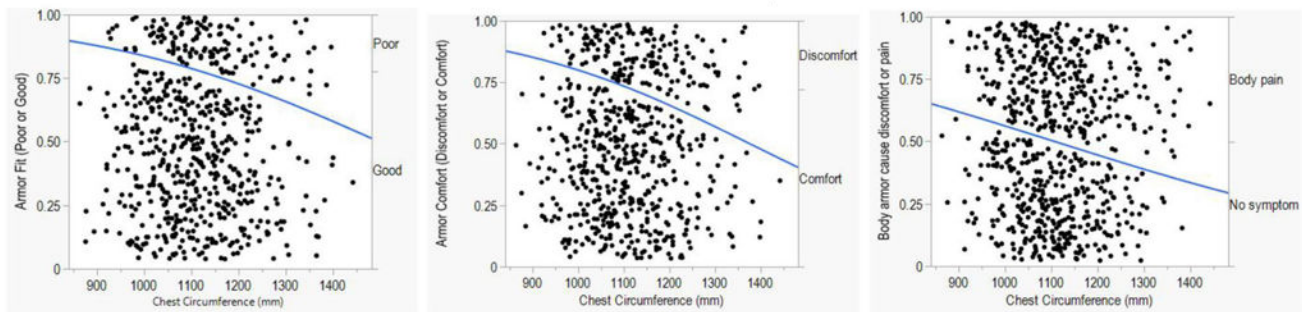
Simple logistic regression models of body dimensions, which predict armour fit, armour comfort, and armour-caused pain for women and men.

		Women			Men		
Item	**Variable**	**Armour fit**	**Perceived discomfort**	**Armour-caused pain**	**Armour poor fit**	**Perceived discomfort**	**Armour-caused pain**
1	Chest breadth	**X+ (0.031)**	**X+ (0.028)**	0.094	**X+ (0.001<)**	**X+ (0.001<)**	**X+ (0.002)**
2	Chest circumference	**X+ (0.009)**	**X+ (0.006)**	0.097	**X+ (0.001<)**	**X+ (0.001<)**	**X+ (0.002)**
3	Chest depth	**X+ (0.013)**	**X+ (0.007)**	0.112	**X+ (0.001<)**	**X+ (0.001<)**	**X+ (0.016)**
4	Sitting height	0.115	0.093	0.661	**0.033**	0.231	0.476
5	Stature	X- **(0.023)**	0.499	0.357	**0.035**	0.254	0.185
6	Waist breadth, sitting	**X+ (0.023)**	**X+ (0.012)**	0.080	**X+ (0.001<)**	**X+ (0.001<)**	**X+ (0.005)**
7	Waist circumference at Om	**X+ (0.031)**	**X+ (0.013)**	**X+ (0.038)**	**X+ (0.001)**	**X+ (0.001<)**	**X+ (0.012)**
8	Waist front length, sitting	0.585	0.977	0.070	**X+ (0.005)**	**X+ (0.036)**	**X+ (0.022)**
9	Weight (kg)	0.219	**X+ (0.021)**	**X+ (0.030)**	**X+ (0.001<)**	**X+ (0.001<)**	**X+ (0.002)**
10	Body mass index (BMI)	**X+ (0.021)**	**X+ (0.004)**	0.055	**X+ (0.001<)**	**X+ (0.001<)**	**X+ (0.003)**
11	Front lateral length, standing	0.955	0.896	0.231	X+ **(0.012)**	X+ **(0.007)**	0.006

Item	Variable	Women			Men		
		Armour fit	Perceived discomfort	Armour-caused pain	Armour poor fit	Perceived discomfort	Armour-caused pain



Prob (Armour fit = 'Good') = 1− (1/(1 + exp (4.55125433 − 0.0041079 * chest circumference)))
Prob (Armour comfort = 'Comfort') = 1− (1/(1 + exp (4.47526942 − 0.0042947 * chest circumference)))
Prob (Armour caused pain = 'No symptom') = 1− (1/(1 + exp (1.87527522 − 0.0026925 * chest circumference)))
Chest circumference is an important predictor of armour fit, armour comfort, but not body pain for women.



Prob (Armour fit = 'Yes') = 1- (1/(1 + exp (4.94560689 − 0.0033018 * chest circumference)))
Prob (Armour comfort = 'Comfort') = 1- (1/(1 + exp (5.06383006 − 0.0036791 * chest circumference)))
Prob (Armour caused pain = 'No symptom') = 1− (1/(1 + exp (2.59505992 − 0.0023441 * chest circumference)))
Chest circumference is an important predictor of armour fit, armour comfort, and body pain for men.

The significance levels for each body dimension are listed in the table by gender. The *logistic plots for chest circumference* for armour fit, armour comfort, and armour-caused pain for each gender are included at the bottom of the table as examples to illustrate the effect of body dimensions. Bold values indicate p values of 0.05 or less.

The X + sign corresponds to the X + mark in Table 14, indicating that simple logistic regression conforms that the *armour poor fit*, *uncomfortable with armour*, and *armour-caused pain* groups had a larger mean of the body dimension than their *counterparts* (i.e., armour good fit, comfortable with armour, and no armour-caused pain groups).

The X – sign corresponds to the X- mark in Table 14, indicating: The *armour poor fit* group had a smaller mean of the body dimension than the *armour good fit* group.