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REVIEW ARTICLE

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The comfort and functional performance of personal protective equipment for police officers: a systematic scoping review

Sean Hudson, Leanne Ridland, Joanna Blackburn, Leanne Monchuk and Karen Ousey

School of Human and Health Sciences, University of Huddersfield, Huddersfield, UK

ABSTRACT

This scoping review aimed to identify and summarise evidence on the comfort and functional performance of police officer personal protective equipment (PPE). The Arksey and O'Malley (2005) five-stage framework for scoping reviews was followed. PubMed, CINAHL, Scopus, and Web of Science were searched, and 35 articles were included in the review. The findings show that increased police PPE mass increases heart rate, metabolic energy expenditure, and perceived exertion in response to exercise. Unisex armour designs cause increased discomfort for females with larger bra sizes. PPE reduces joint-specific range of motion, with the design and location impairing movement more than mass. Jumping and sprinting performance is decreased with heavy PPE but unaffected by lighter protection, while agility is compromised with most forms of protection. Future research is needed on the fit and function of PPE for specialist police units, such as mounted police, along with further investigations on how fit can affect functional performance.

PRACTITIONER SUMMARY

This paper identifies and reviews existing evidence on the comfort and functional performance of police officer personal protective equipment (PPE). This is significant because it summarises and categorises key concepts that underpin research in this area, whilst highlighting gaps in the current knowledge and areas for future research.

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KEYWORDS
Police; personal protective equipment; body armour; performance; comfort

Introduction

The main duty of police officers in the UK is to protect the public through crime detection and prevention Brown (2021). In doing so, they perform a variety of tasks, from desk-based work to pursuing suspects (Orr et al. 2020). Due to the varied and physical nature of law enforcement, which ranges from restraining offenders (Bonneau and Brown 1995, Orr et al. 2020) to riding horses (Orr et al. 2023), police officers are at high risk of physical injury while at work. To reduce the risk of injury, police personnel are often required to wear personal protective equipment (PPE) during occupational tasks (Malbon et al. 2020). PPE describes any equipment worn or held by a person at work to reduce risks to their health and safety (UK Health and Safety Executive 2023) and can range from wearing gloves on an industrial assembly line (Chang, Wang, and Lin 1999) to astronauts wearing space suits to protect them from the extreme conditions of space (Abramov, Moiseyev, and Stoklitsky 2001). For police officers, PPE can include equipment such as body armour, helmets, duty belts, tactical vests, and limb protection (Lewis et al. 2017). Police officers tend to wear PPE that is designed to protect them from threats related to their specific duties (Lewis et al. 2017), so the amount and type of PPE varies between roles, with the additional mass ranging from 3.5 kg for officers on general duty (Dempsey, Handcock, and Rehrer 2013) to 22 kg for specialist tactical police officers (Carbone et al. 2014).

Carrying more/heavier equipment can increase physical exertion and reduce occupational task performance (Knapik et al. 1997), which could lead to a trade-off between increased protection and reduced functional performance for police officers. The size and fit of PPE also appears be an important factor for functional performance, with poor fitting PPE negatively affecting performance in the military (e.g. Armstrong et al. 2019, Coltman et al. 2020), fire and rescue service (e.g. Park and Langseth-Schmidt 2016), and

CONTACT Sean Hudson S.Hudson@hud.ac.uk School of Human and Health Sciences, University of Huddersfield, Huddersfield, UK.

aerospace (e.g. Fineman et al. 2018). Specifically, poor fitting PPE has been shown to reduce reaction time (Choi et al. 2016), decrease range of motion (Coltman et al. 2020), and decrease pulmonary function (Armstrong et al. 2019). Although PPE differs between occupations, due to different risks to health and safety, it seems likely that poorly fitting PPE would also negatively impact police officer performance, as it has been shown to inhibit task performance across several occupational domains (military, healthcare, firefighting, aerospace, and manufacturing) (Brisbine et al. 2022).

Tomes, Orr, and Pope (2017) systematically reviewed the impact of law enforcement body armour on physical performance and reported increased physiological measures of workload (Majumdar et al. 1997, Caldwell et al. 2011), decreased balance and mobility (Dempsey, Handcock, and Rehrer 2013), compromised trunk posture though increased flexion or extension during tasks (Phillips, Bazrgari, and Shapiro 2015, Phillips, Shapiro, and Bazrgari 2016, Lenton et al. 2016), increased perceived exertion (Larsen et al. 2012, Ricciardi, Deuster, and Talbot 2007, Caldwell et al. 2011), and mildly elevated core body temperatures (Caldwell et al. 2011, Larsen et al. 2012). However, ten out of the sixteen studies reviewed by Tomes, Orr, and Pope (2017) focused on military body armour only, which could be considered a major limitation, as standard military body armour is generally heavier than the protective equipment worn by police officers and has been associated with poorer functional movement, agility, and subjective comfort compared to police PPE (Orr, Schram, and Pope 2018). Furthermore, the variety of tasks and roles that police officers perform differ from those of military personnel, so the body armour should not be considered interchangeable between the occupations (Orr, Schram, and Pope 2018). Work is needed to identify and evaluate current evidence on the impact of police specific PPE on functional performance and subjective comfort during tasks related to police activities. As such, the aim of this scoping review was to identify the existing research-based evidence on the comfort and functional performance of police specific protective equipment.

Method

Protocol

This systematic scoping review was conducted following the five-stage framework developed by Arksey and O'Malley (2005), which consist of (1) identifying the research question, (2) identifying relevant studies, (3) study selection, (4) charting data, and (5) collating, summarising and reporting the results. The review is also reported in accordance with the Preferred Reporting for Systematic Reviews and Meta-Analysis extension for Scoping Reviews (PRISMA-ScR) (Tricco et al. 2018).

Stage 1: Identifying the research question

The aim of this review was to identify existing research on the comfort and functional performance of police officers wearing PPE. This broad aim was determined through discussion amongst the research team and was guided by the following questions:

1. How do police officers perceive the suitability of their PPE?
2. What is known about the impact of police specific PPE on occupational performance?

Stage 2: Identifying relevant studies

Search strategy

Literature searches were conducted in the electronic databases of PubMed, EbscoCINAHL, Scopus, and Web of Science. All searches were conducted in July 2022 and repeated for records published after this date in March 2023. The repeated search was only conducted in PubMed, EbscoCINAHL, and Scopus due to access restriction to Web of Science. The search terms ('body armour' OR 'protective equipment' OR 'personal protective equipment') AND ('police' OR 'police officer' OR 'riot police' OR 'law enforcement' OR 'prison officer' OR 'prison guard' OR 'security service') were used in each database. Searches were conducted by a single author (SH) and were saved in Rayyan reference manager software (http://rayyan.qcri.org) for all members of the research team to review.

Stage 3: Study selection

Eligibility criteria

Duplicate articles were removed, and the titles and abstracts of the remaining articles were screened for relevance by one reviewer (SH). The full texts of the remaining articles were then examined using the following eligibility criteria: (1) original article written in English; (2) abstracts available for screening; (3) included a form of protective body worn equipment used by police officer personnel; (4) investigated the effects of protective equipment on physical performance, cognitive performance, occupationally relevant tasks, subjective perceptions of comfort, mobility, balance, or movement biomechanics.

Articles were excluded from the review if they: (1) could be classified as grey literature (such as theses and dissertations - conference proceedings were included if sufficient detail); (2) took the form of a review article; (3)

did not include body worn protective equipment as an independent variable; (4) focused on testing protective equipment used in chemical, biological, nuclear, or high-yield explosive environments; (5) did not include human participants; (6) focused on material properties; (7) only investigated auditory or respiratory protection.

Stage 4: Charting the data

The general characteristics (i.e. year of publication, geography, sample size, and cohort), type of personal protective equipment investigated, study protocol, variables measured, and the main findings were extracted from the selected articles and tabulated. This task was completed by all five authors (SH, KO, JB, LM, LR). Studies were categorised into overarching research topics, determined by their aims and outcome measures. This enabled major themes and gaps in the literature to be identified.

Stage 5: Collating, summarising, and reporting the results

The general characteristics of the included studies were summarised to provide an overview of the number of studies, year of publication, geography, and the types of PPE. The descriptive characteristics were summarised in tables to provide an overview of the evidence. This analysis allowed major themes and gaps in the literature to be identified. These themes were physiology (e.g. metabolic energy expenditure), thermophysiological performance, occupational task performance (e.g. sprint speed, jump height, entering and exiting a vehicle), biomechanics and mobility, and subjective perceptions.

Results

Search and selection

The PRISMA flow chart for detailing the search and selection procedures is shown in Figure 1. The searches identified a total of 683 articles. Following the removal of duplicates (n=284), the titles and abstracts of 399 articles were screened and 266 articles were excluded for not being relevant to the scoping review. The full texts of the remaining 132 articles were then screened using the eligibility criteria and 35 were included in the review.

Characteristics of the included studies

A total of 8,089 individuals participated in the 35 studies, although 6,818 of those were from two studies (Malbon et al. 2020, Larsen et al. 2018). The majority of studies described their participants as police officers (n=27). Two studies described participants as university students/staff, two studies described participants as civilians and four studies did not describe the participants' background. There has been a considerable increase in research on personal protective equipment for police officers in the last decade, with 94% (33 out of 35) of studies being published since 2010. Studies were identified from nine countries: Australia (n=9), USA (n=8), UK (n=4), Sweden (n=4), Brazil (n=3), Germany (n=3), New Zealand (n=2), and Canada (n=1). Eight studies described participants as wearing full police officer uniforms, four of which studied riot or special weapons police uniforms. Of the twenty-seven studies that investigated specific items of equipment only, twenty-five studies included torso protection (e.g. protective vests/body armour) (71% of all studies included in the review), ten studies included duty belts (29%), two included upper arm protection (6%), and one included helmets (3%).

Organisation of data

The identified studies included data on physiology (e.g. metabolic energy expenditure) (n=7) and thermophysiological performance (n=5), occupational task performance (e.g. sprint speed, jump height, entering and exiting a vehicle) (n=12), biomechanics and mobility (n=13), and subjective perceptions (n=13). Seven studies included data for multiple topics. These topics were classified by the lead researcher and agreed by the research team.

Physiology and thermophysiology

The protective equipment worn by police officers was found to increase heart rate in five of the studies included in this review (Dempsey, Handcock, and Rehrer 2013, Dempsey, Handcock, and Rehrer 2014, Divencenzo et al. 2014, Ehnes et al. 2020, Roberts and Cole 2013) and metabolic energy expenditure, measured as estimated VO_2 over a 1.5 mile run (Divencenzo et al. 2014) and $\%VO_{2max}$ during a 5 minute run (Dempsey, Handcock, and Rehrer 2013, Dempsey, Handcock, and Rehrer 2014) (Table 1). Training status has been shown to effect $\%VO_{2max}$ when wearing PPE, with Zwingmann et al. (2021b) reporting a significantly lower $\%VO_{2max}$ at volitional exhaustion for endurance and strength trained individuals compared to untrained individuals during a graded running test.

Heavy full body protective equipment (20.9 kg) has been shown to increase core body temperature compared to wearing no protection during exhaustive

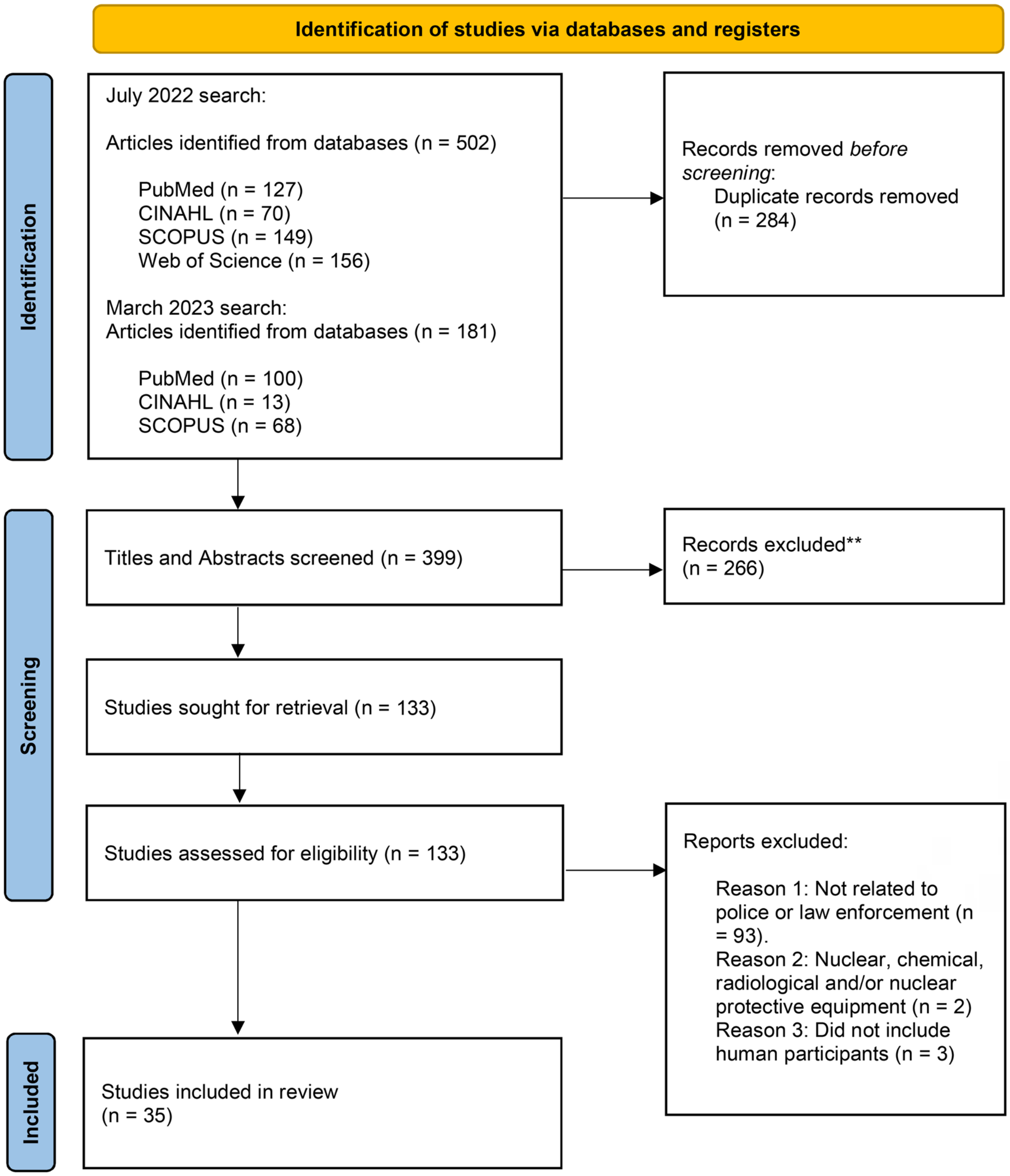

Figure 1. PRISMA flow diagram of the search and study selection process.

running exercise (Zwingmann et al. 2021a). However, there appears to be no difference in core body temperature between PPE and non-PPE conditions with lighter protection (~3kg) during lower intensity activities such as walking for 120 minutes (Pyke, Costello, and Stewart 2015) or jogging on the spot for up to 5 minutes (Roberts and Cole 2013). There also appears to be negligible heat strain (core body temperature and heart rate) for police officers working in armoured vehicles when wearing protective equipment in sub-tropical climates (Stewart and Hunt 2011). The incorporation of an ambient air induction systems into light (~3kg) police body armour might decrease heat strain in hot environments (WBGT ≥ 30 °C) through lower core body temperature (Ryan et al. 2014).

Occupationally relevant task performance

Table 2 shows the studies that included measures of occupationally relevant task performance. Vertical jump height was found to decrease from unloaded trials in two studies, with police officer PPE weighing 8.1–8.3 kg (Marins et al. 2020a) and 16 kg (Zedler and Goldmann 2022). However, Orr, Schram, and Pope

Table 1. Studies that have investigating the effect of police PPE on physiology and thermophysiology (including measures of thermal comfort and thermal sensation).

Study	Participants	Personal protective equipment condition	Method/Protocol	Measurements	Key findings
Dempsey, Handcock, and Rehrer (2013)	52 males. Age: 37 ± 9.2 years; height: 1.81 ± 0.06 m; mass: 90.2 ± 11.6 kg. New Zealand Southern Region District Police.	1. Stab Resistant Body Armour (SRBA) plus appointments (7.65 ± 0.73 kg). 2. Exercise clothing.	5 min run at 13km/h (0% gradient).	HR; VO_2; RER.	• Participants worked harder (increased max HR, increased VO_2, increased RER) in 1) during the 5 min run.
Dempsey, Handcock, and Rehrer (2014)	52 males. Age: 37 ± 9.2 years; height: 1.81 ± 0.06 m; mass: 90.2 ± 11.6 kg. New Zealand Southern Region District Police.	1. Stab Resistant Body Armour (SRBA) plus appointments (7.65 ± 0.73 kg). 2. Exercise clothing.	5 min run at 13km/h (0% gradient).	HR; VO_2; RER.	• Mean %HRmax, %VO_2max, RER were all increased during the final minutes of the 5 min run in 1).
Divencenzo et al. (2014)	12 (6 male, 6 females). Age: 24.3 ± 3 years; height: 1.73 ± 0.10 m; mass: 73.8 ± 11.8 kg. University students and local community members.	1. Exercise clothing + protective vest and duty belt with weight to mimic equipment accessories (6.2 - 6.7 kg, depending on size). 2. Exercise clothing.	Test battery to simulate common police activities: • walking patrol • running after suspect • walking up stairs Total exercise time for each session = 22 mins.	HR; VO_2; RER.	• 1) increased HR and VO_2 during the simulated police exercise. The difference for VO_2 occurred for the walk, jog and stepping activities. The difference in HR were for the walk and step activities (jog was close to significance, p = 0.08). • There was no difference in RER between conditions.
Ehnes et al. (2020)	25 (15 males, 10 females). Age: 26 ± 5 years; height: 1.75 ± 7.5; mass: 74.9 ± 12.8 kg.	1. Police duty ensemble (PDE) - concealable body armour, patrol uniform, duty belt with small equipment - Total PDE mass = 10.3 kg. 2. Physical training ensemble (PTE) - t-shirt, shorts & running shoes. 3. Part 2: PTE and PDE conditions, as well as a weighted duty belt condition (WB) (WB mass = 7.5 kg).	Part 1: Graded treadmill exercise test to volitional exhaustion. Walking at 5.6 km/h with 2% grade increases every 2 mins. The stage at 4% grade was extended to 6 mins to allow measurement of steady state. Part 2: A pursuit and restraint circuit to simulate police officers chasing and apprehending a suspect.	Part 1: HR; VO_2; V_E; Inspiratory capacity. Part 2: HR.	Part 1: • Higher VO_2, V_E, and HR in PDE compared to 2) in the steady state trial. • No difference in peak absolute VO_2 between 1) and 2) for peak physiological response (in exhaustion stage of trial). • No difference in VE between 1) and 2) for peak response. Part 2: • No significant difference in HR or perceived exertion between PPE conditions.
Marins et al. (2020)	13 males. Age: 36.8 ± 3.7 years; height: 1.80 ± 0.06 m; body mass: 89.0 ± 10.7 kg. Federal Highway Policemen.	1. Standard operating uniform of the Department of Federal Highways Police (DFHP) (Brazil) with a long gun (additional load = 5.2 kg). 2. Standard equipment plus the "normal" PPE provided by the DFHP (body armour, tactical belt, accessories, and training gun) - total mass of between 11.8 and 12.0 kg (depending on vest size).	The Occupational Physical Activity Test (7 tasks): • Disembark from a car and sprint with a gun • Progression between barricades with long weapon • Vertical jump over barrier • Long jump • Dummy drag • Collect and load cones (agility) • Vehicle push	HR; HRV; Blood lactate.	• No difference in HRmax or HRV between conditions during the occupational tasks. • Increased blood lactate immediately after the occupational tasks in 2) compared to 1).
Marins et al. (2020)	19 males. Age: 38.5 ± 4.1 years; height: 1.78 ± 0.07 m; body mass: 87.2 ± 11.3 kg. Federal Highway Policemen (mean service time = 10.1 years).	1. Standard operating uniform of the Department of Federal Highways Police (DFHP) (additional load = 1.5 kg). 2. Standard equipment plus the "normal" PPE provided by the DFHP (body armour, tactical belt, accessories, and training gun) - total mass between 8.1 and 8.3 kg (depending on vest size).	Maximal Progressive Test (MPT) – Graded treadmill exercise test to volitional exhaustion (started at 8 km/h at 1% gradient and increased by 1 km/h every 2 mins until exhaustion).	HR; VO_2; Blood lactate; RER.	• Increase in HRmax in 2) (185 ± 8 b/min) compared to 1) (188 ± 8 b/min) during the MPT. • No difference in blood lactate between conditions. • No difference in VO_2 or RER between conditions.

(*Continued*)

Table 1. Continued.

Study	Participants	Personal protective equipment condition	Method/Protocol	Measurements	Key findings
Pyke, Costello, and Stewart (2015)	8 males. Age: 26 ± 6 years; height: 1.7 ± 0.06 m; body mass: 76 ± 6 kg.	1. Tactical trousers and utility belt. 2. Control condition plus body armour (mass = 2.977 kg). 3. Control condition plus covert body armour (mass = 2.571 kg)	120 mins treadmill walking at 4.7 km/h in an environmental chamber (31 °C, 60% relative humidity).	HR; Core body temp; Skin temp; Body mass; Thermal comfort; Thermal sensation.	• No difference in core temperature, HR, and skin temperature between conditions. • 3) produced a greater amount of body mass change compared to 1) and 2). • No significant difference in thermal comfort or thermal sensation between conditions.
Roberts and Cole (2013)	Study 1: 40 males. Age: 20.8 ± 1.7 years SD). Undergraduate students. Study 2: 20 participants. Age: 26.6 ± 6.2 years. University staff and members of the university gym facility.	1. Body armour vest (S203 Tactical Vest) and helmet (PAGST). 2. No armour or helmet	Study 1 & 2 Four conditions: • Brief exercise (1 min jog on spot). • Brief exercise wearing body armour. • Extended exercise (Study 1: 5 min jog and sprinting; Study 2: 4 min jogging and sprinting). • Extended exercise wearing body armour.	HR; Core body temp.	Study 1 & 2: • HR increased in 1) compared to 2) • No difference in core body temp between PPE conditions.
Ryan et al. (2014)	9 males. Age: 27 ± 4 years; height 1.80 ± 0.07 m; body mass: 79.8 ± 12.1 kg.	1. Non modified police standard issue body armour (~3 kg). 2. Modified standard issue body armour with a custom-built ambient air induction system.	Repeated cycles of 12 min walking and 3 min of arm curls (14.3 kg), with 5 min rest after every other cycle, for a total of 60 minutes. WBGT = 30 °C.	HR; Core body temp; Thermal comfort.	• No difference in heart rate between conditions 1) and 2). • No difference in core body temperature between conditions 1) and 2) at the end of the work bout. • Core body temperature increased at a quicker rate in 1) compared to 2). • No significant differences in thermal comfort between conditions, although comfort scores in 2) approached being significantly lower than 1) at 45 and 60 mins.
Stewart and Hunt (2011)	12 males. Age: 41 ± 7.9 years; height 1.85 ± 0.05 m; body mass: 107 ± 21.3 kg. Armoured Vehicle Officers (AVO).	1. Normal uniform and personal body armour.	Shift work lasting 7.76 ± 0.8 hours with 27.9 ± 3.4 work tasks being performed that lasted 8.6 ± 1.8 mins. This totalled 50.1 ± 6.8% of the shift performing tasks outside of an air-conditioned vehicle.	Core body temp; Urine specific gravity; Self-reported heat illness.	• During the shift, core body temperature increased 0.8 ± 0.2 °C • No change pre, mid and post shift in urinary specific gravity; a variety of fluid consumed 2.1 ± 0.8 L • 9 AVOs reported between 1–8 heat illness symptoms that were experienced.
Zwingmann et al. (2021)	45 participants. Age: 25 ± 4 years; height: 1.81 ± 0.07 cm; body mass: 82 ± 12 kg.	1. PPE worn by riot police (20.9 kg). 2. Exercise clothing.	Graded exercise test to volitional exhaustion.	Sweat rate; Core body temp; EE.	• Sweat rate was 91% higher in 1) than in 2). • Body temperature was higher in 1) during submaximal and maximal exercise intensity. • 1) increased EE by 34% and 37% at 5.8 and 6.5 km/h, respectively.

*HR = Heart rate; EE = Energy expenditure; VO_2 = Oxygen consumption; V_E = Minute ventilation; RER = Respiratory exchange ratio; WGBT = wet bulb globe temperature; HRV = Heart Rate Variability.

Table 2. Studies that have investigating the effect of police PPE on occupational task performance.

Study	Participants	Personal Protective Equipment Conditions	Method/Protocol	Measurements	Key Findings
Dempsey, Handcock, and Rehrer (2013)	52 males. New Zealand Southern Region District Police.	1. Stab Resistant Body Armour (SRBA) plus appointments (7.65 ± 0.73 kg). 2. Exercise clothing.	5 tasks: Timed balance task; Acceleration task to simulate exiting a vehicle; Chin-ups to volitional exhaustion; Grapple task; Manoeuvrability task. Tasks repeated following 5 min run at 13km/h (0% gradient).	Mobility task scores: (time to completion for all tasks, except chin-ups).	• The mobility tasks were negatively affected by 1) with mean decreases in performance ranging from 13–42%. • Mobility task performance was further reduced (6–16%) after the run, but only in 1).
Dempsey, Handcock, and Rehrer (2014)	52 males. New Zealand Southern Region District Police.	1. Stab Resistant Body Armour (SRBA) plus weight representative of a standard police duty belt (7.65 ± 0.73 kg). 2. Exercise clothing.	4 jump and landing tasks: CMJ; Drop landing from 0.75m; Drop landing immediately followed by vertical jump; Drop landing with distraction at touchdown. Tasks repeated following 5 min run at 13km/h (0% gradient).	Jump height.	• Vertical jump and drop jump height has 13% lower when participants were loaded.
Ehnes et al. (2020)	25 (15 males, 10 females).	1. Part 1: Police duty ensemble (PDE; see Table 1 for details). Total PDE mass = 10.3 kg. 2. Physical training ensemble (PTE) –exercise clothing. 3. Weighted duty belt condition (WB) (WB mass = 7.5 kg).	A pursuit and restraint circuit to simulate police officers chasing and apprehending a suspect.	Performance time.	• Performance time unchanged in the 3) compared to 2). • Performance time significantly increased (worse) in 1) compared to both 2) and 3).
Lowe et al. (2016)	9 males. Age: 18–25 years.	1. Weighted vest equal to ~11%, 13%, and 16% body mass 4 days/week.	3 weeks wearing external load for 8 h/day (ELDL). 3 weeks without wearing weighted vest (CON). Performance tests before and after ELDL and CON wearing a 12 kg vest. Performance tests included: Timed stairs climb; Zig-zag sprint; 25 m casualty drag (84 kg); 200-yard shuttle run (8 × 25yards).	Performance tests with and without weighted vests.	• All tasks displayed trends of improvement from baseline to post ELDL, followed by modest drops in performance during CON.
Lewinski et al. (2015)	20 males. Law enforcement students.	1. No duty belt. 2. Duty belt (9.07kg).	Two maximal effort sprints (9.1 m) from four starting positions: Forward (control); Backwards; 90 degrees left; 90 degrees right. There were also two focal points, used to simulate officers maintaining focus on a suspect or oncoming vehicle during sprints.	Sprint velocity; Sprint acceleration.	• Decreases in velocity and acceleration with 2). • No effects were found as a result of starting position or focal point.
Marins et al. (2020)	19 males Federal Highway Policemen (mean service time = 10.1 years).	1. Standard operating uniform of the Department of Federal Highways Police (DFHP) (additional load = 1.5 kg). 2. Standard equipment plus the "normal" PPE provided by the DFHP (body armour, tactical belt, accessories, and training gun) - total mass between 8.1 and 8.3 kg (depending on vest size).	Physical fitness measures: Maximal Progressive Test (MPT) – (See Table 1 for details); Trunk isometric endurance (TIE); Squat jump (SJ); Counter-movement jump (CMJ); Standing long jump (SLJ); Fixed bar isometry; Illinois agility test (IAT); Fletcher test (FT).	Performance outcomes on the physical fitness tests.	• Decreases in physical performance due to the use of 2), such as decreases in upper-limb strength, trunk resistance, jump height, agility, and time to exhaustion.
Marins et al. (2020)	13 males.	1. No PPE condition: Officers standard operating uniform of (additional load = 5.2 kg). 2. PPE condition: Ballistic vest police belt with the attached accessories - total mass of between 11.8 and 12.0 kg (depending on ballistic vest size).	The Occupational Physical Activity Test (circuit composed of 7 tasks): Disembark from a car and sprint with a gun; Progression between barricades with long weapon; Vertical jump over barrier; Long jump; Dummy drag; Collect and load cones (agility); Vehicle push.	Performance outcomes on the Occupational Physical Activity Test (total and individual time of each task).	• 2) reduced performance in specific occupational circuit

(*Continued*)

Table 2. Continued.

Study	Participants	Personal Protective Equipment Conditions	Method/Protocol	Measurements	Key Findings
Orr, Schram, and Pope (2018)	10 (6 females, 4 males). Volunteer police officers.	1. Military body armour (6.4 kg). 2. Law enforcement body armour (2.1 kg).	Tests included: CMJ; Illinois Agility Test; Vehicle exit and 5 m sprint; 10 m sprint to simulated victim and 10 m recovery drag.	Vertical jump height; Agility test time; Task simulation times (vehicle exit; victim recovery).	• Body armour type did not affect vertical jump, vehicle exit and 5 m sprint times, or victim recovery times. • 1) was associated with significantly slower times to complete the agility task.
Orr et al. (2019)	27 female police officers.	1. Unloaded. 2. 10 kg vest.	Change of direction (COD) (Illinois agility test).	Agility completion time.	• COD was slower with 2) compared to 1). • Performance in 1) was strongly associated with performance in 2).
Schram et al. (2018)	11 (5 females, 6 males) Police officers.	1. Normal station wear. Three types of Individual Light Body Armour Vests (ILAV): 2. ILAV A: 4.68% body mass. 3. ILAV B: 4.05% body mass. 4. ILAV C: 3.71% body mass.	Victim drag. Car exit and 5-metre sprint. Step down and marksmanship task.	Task performance.	• Results showed that performance in each task did not vary between any of the ILAV or normal station wear conditions. • The results suggest that none of the ILAVs used in this study were heavy enough to significantly affect task performance. • There was less variability in the marksmanship task with 3).
Thomas et al. (2018)	12 participants SWAT operators.	1. Unloaded. 2. Tactical equipment (absolute load of 14.2 ± 2.0 kg).	Simulated Tactical Test (STT) and rifle marksman test.	STT and shooting accuracy tested against control and load carriage conditions.	• Time to complete simulated tactical course was increased with 2). • Rifle marksmanship show no change. • 2) reduced task efficiency.
Zedler and Goldman (2022)	29 males, 32 females.	1. Uniform - Ballistic protection vest, helmet, belt, boots, all standard equipment (total mass = 16 kg). 2. No uniform.	20 CMJ's on force plate (8s rest between jumps).	Jump height.	• Jump height decreased with 1).
Zwingmann et al. (2021)	45 participants.	1. PPE worn by riot police (20.9 kg). 2. Exercise clothing.	10m dummy drag and graded exercise test until volitional exhaustion.	Time to complete dummy drag; Time to exhaustion on exercise test.	• Dummy drag and running performance impaired by 14 ± 9 % and 58 ± 7% with 1).

*CMJ = Counter movement jump.

(2018) found no difference in jump height between military protective body armour weighing 6.4 kg and law enforcement body armour weighing 2.1 kg. Different types of police office body armour (mass ranging from 2.9–5.5 kg) have also been shown to have no effect on jump height (Schram et al. 2019). Sprint performance (Schram et al. 2019, Orr, Schram, and Pope 2018) and vehicle exit acceleration (Schram et al. 2018b) has also been shown to not differ between different types of body armour with weight differences ≤ 4 kg. However, body armour compared to no armour appears to reduce acceleration performance in simulated vehicle exiting tasks (Dempsey, Handcock, and Rehrer 2013). Agility appears to decrease with PPE compared to not wearing PPE with slower changes of direction (Orr et al. 2019, Marins et al. 2020a). In line with this, occupational ability course and work simulation performance completion times are increased with PPE (Thomas et al. 2018, Marins et al. 2020a, Dempsey, Handcock, and Rehrer 2013, Ehnes et al. 2020). Time to exhaustion during graded exercise tests also appears to decrease when wearing police officer PPE ((Zwingmann, Below, et al., 2021; Zwingmann, Hoppstock, et al., 2021). Studies have shown no effect of police PPE on marksmanship (Thomas et al. 2018, Schram et al. 2018b).

Biomechanics and mobility

Studies that have included biomechanics and mobility measures are shown in Table 3. Joint specific range of motion appears to generally decrease with PPE (Blackledge et al. 2009, Larsen, Tranberg, and Ramstrand 2016, Schram et al. 2020). Both the design and weight of PPE appear to restrict range of motion with Blackledge et al. (2009) demonstrating reduced shoulder and thorax rotation with external body armour compared to concealed body armour, with the external armour being heavier and having additional shoulder protection. Restricted shoulder mobility has also been reported with light police body armour vests compared to no PPE (Schram et al. 2020). Functional Movement Screen (FMS) Scores appear to be decreased (reduced movement ability) with military body armour compared to police armour (Orr, Schram, and Pope 2018) and Schram et al. (2020) reported no difference in total FMS scores between different designs of light police body armour vests (3.24 – 4.12 kg) compared to wearing no armour. FMS scores do appear to decrease when police officers carry all protective equipment on a duty belt compared to distributing some of the equipment to a vest, although the vests were shown to inhibit squat, hurdle, lung and shoulder movement (Jewett et al. 2023). Mobility task performance (balance task, acceleration task, chin-ups, grapple task) with body armour is decreased from 13–42%, with further decreases in the performance of these mobility tasks following 5 minutes of running (Dempsey, Handcock, and Rehrer 2013). Increasing the mass of the body armour increases ground reaction forces (Dempsey, Handcock, and Rehrer 2014) and joint moments at the ankle (Larsen, Tranberg, and Ramstrand 2016). Balance is impacted by the distribution of mass with an uneven distribution of equipment around the body negatively effecting static and dynamic balance (Orr, Schram, and Pope 2018).

Comfort and subjective perceptions

Most studies reported an increase in ratings of perceived exertion (RPE) with PPE (Zwingmann et al. 2021b, Dempsey, Handcock, and Rehrer 2013, Dempsey, Handcock, and Rehrer 2014, Ehnes et al. 2020), but this is not a unanimous finding (Divencenzo et al. 2014, Marins et al. 2020a) (Table 4). Divencenzo et al. (2014) reported no difference in RPE, measured using a Borg Scale (6–20 points), between PPE and no-PPE during steady-state walking, jogging, and stepping activities. However, they did find significantly increased session RPE with PPE, measured using an OMNI scale (0–10 points) following all three exercise modes. The inclusion of an airflow induction system into body armour might reduce RPE in hot environments (Ryan et al. 2014). The majority of studies measuring comfort have used some form of visual analogue scale (Divencenzo et al. 2014, Schram et al. 2018a, Ramstrand et al. 2016, Larsen, Ramstrand, and Tranberg 2019) and/or survey methods (Larsen, Ramstrand, and Tranberg 2019, Larsen et al. 2018, Ramstrand et al. 2016, Malbon et al. 2020, Niemczyk, Arnold, and Wang 2020). Increased discomfort (Malbon et al. 2020, Malbon et al. 2022, Divencenzo et al. 2014, Ramstrand et al. 2016, Schram et al. 2018a) and pain (Larsen et al. 2018) have been commonly reported for the areas of the body that police PPE is worn. However, the body armour used by police officers has been reported as being more comfortable than military body armour (Orr, Schram, and Pope 2018). For female officers, the comfort of unisex body armour vests has been reported to be lower for those with larger breasts (Niemczyk, Arnold, and Wang 2020), and sports bras have been rated as more comfortable under female specific PPE vests than underwired bra's, with the type of bra worn underneath PPE suggested to be more

Table 3. Studies that have investigating the effect of police PPE on biomechanics and mobility.

Study	Participants	Personal Protective Equipment Conditions	Method/Protocol	Measurements	Key Findings
Blackledge et al. (2009)	8 males. Experience: 5.81 ± 5.10 years.	Three armour configurations: 1. no armour. 2. concealable body armour. 3. external body armour.	Warm up completed and then fitted with the armour followed by the range of motion tests.	Range of motion (ROM).	• 3) resulted in lower ROM compared to 1) and 2). • Differences in design (e.g. the presence of shoulder protectors) may be responsible for reduced ROM findings.
Dempsey, Handcock, and Rehrer (2014)	52 males. New Zealand Southern Region District Police.	1. Stab Resistant Body Armour (SRBA) plus weight representative of a standard police duty belt (7.65 ± 0.73 kg). 2. Exercise clothing.	4 jump and landing tasks: CMJ; Drop landing from 0.75m; Drop landing immediately followed by vertical jump; Drop landing with distraction at touchdown Tasks repeated following 5 min run at 13km/h (0% gradient).	Ground Reaction Force (impact forces - peak vertical GRF).	• Drop jump ground contact time was significantly longer in 1). • 1) significantly increased peak GRF (13–19%) across all tasks before the 5 min run, with further increases of 4–9% across all landing conditions after the run (increase only present in the 1) after the run).
Hoflinger et al. (2021)	42 males; Military Police Officers Car patrol group (CAR); Motorcycle patrol group (MOT); Administrative group (ADM).	Individual officer PPE (varied based on role): 1. CAR: 8.3 ± 9.0 kg 2. MOT: 13.7 ± 1.1 kg 3. ADM: 4.2 ± 1.0 kg	Stature and peak torque of the trunk measured pre and post 6-hour work shift.	Isometric peak torque (trunk extensor and flexor torque); Spine stature following 6 hours on-duty (either in car, on motorcycle or admin).	• No difference in trunk flexion or extension peak torque between groups. • 3) experienced lower stature loss that 1) and 2). No difference in stature loss between 1) and 2).
Jewett et al. (2023)	32 (31 males, 1 female) Officers from 7 law enforcement agencies in rural regions of the US.	1. PPE (Vest; Nylon duty belt (n = 16); Leather duty belt (n = 16)). 2. No PPE.	Functional Movement Screen (FMS) (Cook et al., 2014).	FMS score.	• Decrease in FMS score (reduced movement ability) in 29 participants in 1) compared to 2). No difference in FMS score for 3 participants between 1) and 2). • Median FMS scores were lower in 1) than 2) for deep squat, hurdle step, in-line lunge, rotary stability, and shoulder mobility. • No difference in FMS scores between participants wearing different types of duty belt in 1).
Kasovic et al. (2020)	275 (186 males, 89 females) Croatian Police Academy officers.	1. Standard police equipment (belt, pistol, ammunition, nightstick, handcuffs). Total mass = 3.5 kg. 2. No equipment.	5 walks across pressure platform.	Stride pattern (stride length, step length, step width, step time, cadence); Peak pressure (forefoot, midfoot, hindfoot).	• Reduced stride length, cadence, and walking speed with1). • Increased stride time and step width with 1). • Increased pressure at the forefoot, midfoot and hindfoot with 1).
Larsen, Ramstrand, and Tranberg (2019)	22 (11 male, 11 female) Swedish Police Officers.	1. Body armour + duty belt (equipment carried in belt). 2. Body armour + load-bearing vest (equipment carried in vest). 3. No PPE.	Sat in a standard police vehicle with each PPE condition while driving a standardised 22 km route (time to completion 25–30 min).	Seated pressure.	• Pressures on the lower back were reduced in 2) compared to 1). • Pressures in the upper back region increased with 2) compared to 1).

Study	Participants	Personal Protective Equipment Conditions	Method/Protocol	Measurements	Key Findings
Larsen, Tranberg, and Ramstrand (2016)	19 (11 males, 8 females) Swedish police officers working on active duty.	1. Body armour + duty belt (equipment carried in belt). 2. Body armour + load-bearing vest (equipment carried in vest). 3. No PPE.	Treadmill walking at self-selected speed. Kinematic and kinetic data collected using and 8 camera motion capture system and two force plates, respectively.	Stride pattern (stride length, stride width, velocity); Trunk, pelvis, hip, knee and ankle joint angles; Hip, knee and ankle joint moment and powers.	• No difference in walking speed or spatio-temporal parameters between conditions. • Range of trunk rotation reduced for both PPE conditions compared to the 3). • Range of hip rotation was more similar to 3) when wearing thigh holster rather than the belt mounted hip holster. • Moments and powers for both left and right ankles were greater for both 1) and 2) compared 3).
Martin et al. (2023)	24 (13 males, 11 females) Non police officers.	1. Police belt (total mass = 7.2 kg). 2. Police tactical vest (total mass = 7.2 kg). 3. No PPE.	Treadmill walking at 4.8km/h and 1.5% incline for 60 seconds.	Surface EMG of the multifidus, rectus femoris, biceps femoris, rectus abdominus.	• Increased average muscle activity in the rectus femoris and multifidous in 1) and 2) compared to 3). • No difference in average muscle activity between 1) and 2).
Orr, Schram, and Pope (2018)	10 (4 males, 6 females) Volunteer police officers.	1. Military body armour (6.4 kg). 2. Law enforcement body armour (2.1 kg).	Tests included: • Postural sway measures • Functional Movement Screen (FMS)	Postural sway; FMS score.	• Both armour types increased sway velocity and sway-path length in the final five seconds compared to the first 5 s of a balance task. • 1) was associated with significantly slower times to complete the agility task and poorer FMS total scores.
Ramstrand et al. (2016)	18 (9 males, 9 females) Active-duty Swedish police officers.	1. Control (no belt or vest). 2. Belt and ballistic protection vest (~6.5 kg). 3. Load bearing vest and ballistic protection vest (~6.9 kg).	9 metres overground walking at self-selected walking speed. PPE condition 3) repeated after 3 months of regularly wearing the equipment.	Stride patterns (walking speed, stride length, cadence, stride width); Trunk, pelvis, and hip joint angles.	• Greater arm abduction in 2) and 3) compared to 1) (indicates arms held out further from the body). • Decreased stride length with 3) compared to 1). • Except for range of motion at the trunk, changes in gait with 3) from 1) decreased after 3 months experience of wearing the equipment.
Schram et al. (2019)	11 (6 male, 5 female) Australian State Police.	1. Normal station wear. Three types of Individual Light Body Armour Vests (ILAV): 1. ILAV A: 4.12 ± 0.65 kg 2. ILAV B: 3.54 ± 0.70 kg 3. ILAV C: 3.24 ± 0.48 kg	Officers wore the ILAV or Normal Station wear for one day while completing power and agility-based tasks including: • Counter Movement Jump • Agility test • 20m sprint	CMJ height; Force; Velocity; Power.	• No differences between any of the ILAVs in peak force, velocity, and power in the CMJ. • There was a higher mean force produced in the CMJ while wearing all three ILAVs.
Schram et al. (2020)	11 (6 male, 5 female) Australian State Police.	1. Normal station wear. Three types of Individual Light Body Armour Vests (ILAV): 2. ILAV A: 4.12 ± 0.65 kg 3. ILAV B: 3.54 ± 0.70 kg 4. ILAV C: 3.24 ± 0.48 kg	Tests included: • Postural sway measures • Functional Movement Screen (FMS)	Balance (total sway, average sway velocity, ML total distance, AP & ML total distance, AP & ML total average velocity, total excursion area, total sway change from AM to PM); FMS score.	• No significant difference in total FMS score between PPE conditions • No significant difference in any balance test results between PPE conditions.

Table 4. Studies that have investigating the effect of police PPE on subjective perceptions of comfort and exertion.

Study	Participants	Personal Protective Equipment Conditions	Method/Protocol	Measurements	Key Findings
Close et al. (2009)	8 males Law enforcement personnel (Mississippi State, USA).	1. Baseline (no body armour). 2. Concealable body armour (CBA). 3. External body armour (EBA).	Five task classifications: • range of motion (neck, back, shoulder) • position changes (sit, stand, kneel) • simple movements (walking forward, walking backward, ingress/egress, figure-8 run & duck) • tactical movements • weapons & equipment handling	Questionnaire completed at end of each task (focus on the extent to which the body armour condition interfered with or inhibited the ability of the participant to complete the task).	• The rating of interference increased from baseline to 2) and from 2) to 3). Specifically arm, shoulder, and neck movement was identified as being restrictive. • 2) condition resulted in significantly higher (better) design ratings and overall opinion ratings than 3).
Dempsey, Handcock, and Rehrer (2013)	52 males. New Zealand Southern Region District Police.	1. Stab Resistant Body Armour (SRBA) plus appointments (7.65 ± 0.73 kg). 2. Exercise clothing.	5 tasks: timed balance task acceleration task to simulate exiting a vehicle chin-ups to volitional exhaustion grapple task manoeuvrability task Tasks repeated following 5 min run at 13km/h (0% gradient)	RPE.	• Increased RPE while loaded during the 5 min run. • There were no differences in unloaded task performance between the phases.
Dempsey, Handcock, and Rehrer (2014)	52 males. New Zealand Southern Region District Police.	1. Stab Resistant Body Armour (SRBA) plus weight representative of a standard police duty belt (7.65 ± 0.73 kg). 2. Exercise clothing.	4 jump and landing tasks: CMJ Drop landing from 0.75m drop landing immediately followed by vertical jump drop landing with distraction at touchdown Tasks repeated following 5 min run at 13km/h (0% gradient)	RPE.	• In the loaded condition, RPE increased during the final minutes of the 5 min run.
Divencenzo et al. (2014)	12 (6 male, 6 females) University students and local community members.	1. Exercise clothing + protective vest and duty belt with weight to mimic equipment accessories. Small protective vest and duty belt weighed 6.2 kg, large protective vest and duty belt weighed 6.7 kg. 2. Exercise clothing.	Test battery to simulate common police activities: • walking patrol • running after suspect • walking up stairs Total exercise time for each session was 22 mins.	RPE; Discomfort (Visual Analogue Scales).	• There was no difference in RPE between conditions (RPE was close to significance, p = 0.085). • 1) significantly increased subjective scores of discomfort and effort.
Ehnes et al. (2020)	25 (15 males, 10 females).	Part 1: 1. Police duty ensemble (PDE; see Table 1 for details) - Total PDE mass = 10.3 kg. 2. Physical training ensemble (PTE) - t-shirt, shorts & running shoes. Part 2: PTE and PDE conditions, as well as a weighted duty belt condition (WB) (WB mass = 7.5 kg)	Part 1: Graded treadmill exercise test to volitional exhaustion. Walking at 5.6 km/h with 2% grade increases every 2 mins. The stage at 4% grade was extended to 6 mins to allow measurement of steady state. Part 2: A pursuit and restraint circuit to simulate police officers chasing and apprehending a suspect.	Part 1: • RPE. Part 2: • Perceptual response.	Part 1: • Higher RPE in 1) compared to 2) in the steady state trial. • No difference in RPE between 1) and 2) for peak response. Part 2: • No difference in perceived exertion between any conditions.
Larsen et al. (2018)	4185 police officers All uniformed active-duty officers.	1. Standard Police Uniform (focus on duty belt and body armour for protective clothing questions).	Online survey based on questions from the Swedish Work Environment Survey (SWES) – 5-point Likert scales.	Multisite musculoskeletal pain for four body regions: • upper back and neck • lower back • shoulders or arms • hips, legs, knees or feet	• The prevalence of multi-site musculoskeletal pain at least 1 day per week within the previous 3 months was 41.3%. • An association between discomfort from wearing mandatory equipment (duty belt and body armour) and multi-site musculoskeletal pain was found. • Sitting for long periods in fleet vehicles was not associated to multi-site musculoskeletal pain.

Study	Participants	Personal Protective Equipment Conditions	Method/Protocol	Measurements	Key Findings
Larsen, Ramstrand, and Tranberg (2019)	22 (11 male, 11 female) Swedish Police Officers.	1. Body armour + duty belt (equipment carried in belt). 2. Body armour + load-bearing vest (equipment carried in vest). 3. No PPE.	Sat in a standard police vehicle with each PPE condition while driving a standardised 22 km route (time to completion 25–30 min).	Discomfort in 20 body regions (100mm visual analogue scale). The Automobile Seating Discomfort Questionnaire.	• Less discomfort when wearing the alternate load carriage system incorporating a load-bearing vest and thigh holster compared to standard load carriage system consisting of a duty belt.
Malbon et al. (2020)	2633 females Police officers.	1. Body armour vest.	Self-reported survey on breast size and bra type on comfort of wearing body armour.	Survey to measure discomfort.	• The predominant bra type worn is underwired (71%) and the predominant UK bra size is 34B (9%). • Predominant areas where the body armour rubbed or caused discomfort were the left and right anterior mammary regions and the posterior lateral sacral region.
Malbon et al. (2022)	31 females Police officers.	1. Underwire bra, sports bra, normal uniform.	• Professional bra fitting session and the supply of an underwired and sports bra that were both best fit and style for the participant. • 3D body measurement scan of each participant in the underwired and sports bra. • The completion of a three-part survey, pre-fitting and then post-fitting wearing each of the bras for a minimum of 10 shifts.	Rubbing/discomfort areas; Bra size; Choice of underwire bra or sports bra.	• Cup size or under bust measurement does not influence where participants identified rubbing or discomfort when wearing PPE. • 71% of participants switched to sports bra when wearing body armour.
Niemczyk, Arnold, and Wang (2020)	A survey of 273 female Victoria Police officers.	1. Ballistic vests.	Survey of female Victoria Police officers Questions included fit, comfort, protection, and fitness for purpose.	Fit of ballistic vests.	• Women with larger breasts experienced more problems with unisex ballistic vests than women with small breasts. • Unisex ballistic vests not suitable for females with larger breasts when combined with commercial sports bras. • Although wire-free bras are recommended for use with ballistic vests, officers with larger breasts reported that they preferred to wear underwire bras. • Sports bras are not designed to be worn under body armour for prolonged periods.
Ramstrand et al. (2016)	18 (9 males, 9 females) Active-duty Swedish police officers.	1. Control (no belt or vest). 2. Belt and ballistic protection vest. 3. Load bearing vest and ballistic protection vest.	9 metres overground walking at self-selected walking speed.	Questionnaire for perceived comfort; VAS scales for comfort in specific body regions.	• Participants felt more comfortable standing, walking, and sitting in a vehicle in 3) compared to 2). • Perceived range of motion was better in 3) compared to 2). • Increased pain in the lower back reported with 2). • More frequent pain in the upper back and neck with 3).

(*Continued*)

Table 4. Continued.

Study	Participants	Personal Protective Equipment Conditions	Method/Protocol	Measurements	Key Findings
Schram et al. (2018)	11 (6 male, 5 female) Australian State Police.	1. Normal station wear. Three types of Individual Light Body Armour Vests (ILAV): 2. ILAV A: 4.68% body mass 3. ILAV B: 4.05% body mass 4. ILAV C: 3.71% body mass	Officers wore the ILAV or Normal Station wear for one day while completing tasks including: • Simulated victim drag • Patrol vehicle exit and a marksmanship shoot	RPE during victim drag; VAS during vehicle exit and marksmanship; Subjective evaluation of each ILAV.	• Less perceived effort required for the victim drag whilst wearing 3) compared to 1), 2), and 3). • A positive impact on performance was perceived for 3) when performing a patrol vehicle exit and sprint task but not for the 2) or 4). • Officers perceived a positive impact of 3) and 1) and a negative impact of 2) and 4) on marksmanship. • Despite all armour types being criticised for discomfort, 3) received lower ratings of discomfort overall, and some positive comments regarding both comfort and performance.
Thomas et al. (2018)	12 participantsSWAT operators.	• Unloaded. • Tactical equipment (absolute load of 14.2 ± 2.0 kg).	Simulated Tactical Test (STT) and rifle marksman test.	RPE.	• 2) had no effect on perceptual fatigue.

*RPE = Rating of Perceived Exertion; VAS = Visual Analogue Scale

important to comfort than cup size or bust prominence (Malbon et al. 2022).

Thermal comfort and thermal sensation appear to be similar between different types of lightweight body armour (~2.5–3 kg) and wearing no body armour when walking in hot and humid environments (31 °C, 60% relative humidity) for up to 120 minutes (Pyke, Costello, and Stewart 2015) (Table 1). Ryan et al. (2014) also reported no significant difference in thermal comfort with the addition of an ambient air induction systems into light (~3kg) police body armour compared to standard issue light armour during 60 minutes of exercise in hot environments (WBGT ≥ 30 °C). However, Ryan et al. (2014) did show that thermal comfort was close to being significantly lower with the air induction system after 45 and 60 minutes of exercise.

Discussion

The aim of this scoping review was to identify and examine the existing evidence on the comfort and functional performance of individuals while wearing police specific protective equipment. Thirty-five studies were included in the review and four major themes were identified. These were physiological and thermophysiological responses, occupational task performance, biomechanics and mobility, and subjective perceptions.

Physiological and thermophysiological responses

Heart rate and VO_2 were the most commonly assessed physiological variables, with several studies reporting an increase in heart rate and VO_2 when wearing PPE compared to exercise clothing (Dempsey, Handcock, and Rehrer 2013, Dempsey, Handcock, and Rehrer 2014, Divencenzo et al. 2014, Ehnes et al. 2020). This is not surprising as PPE adds load to the body, which has been consistently shown to increase heart rate and energy expenditure during submaximal exercise in the wider load carriage literature (e.g. Simpson, Munro, and Steele 2011, Hinde et al. 2017). The mass and placement of additional load has been shown to impact energy expenditure, with loads carried close to the body's centre of mass resulting in a rise of approximately 1% per 1 kg of additional mass when walking (Quesada et al. 2000, Lloyd and Cooke 2000b, Hinde et al. 2017), and greater energetic costs when carrying loads further from the body's centre of mass, such as in the hands (Soule and Goldman 1969, Kamon and Belding 1971) or on the feet (Soule and Goldman 1969, Browning et al. 2007). The majority of research exploring the physiological responses to police protective equipment have focused on torso, waist or full body PPE (Table 1). Zwingmann et al. (2021a) found that full body riot police PPE, which includes additional load carried near the centre of mass and on the extremities (helmet, ballistic vest, duty belt, forearm, knee and shin protectors, and combat boots), results in a greater than proportional increase in energy expenditure, with increases in energy expenditure of 34% and 37% when carrying 20.9 kg of PPE at speeds of 5.8 and 6.5 km/h, respectively. This is unsurprising given that adding 8 kg to the thigh, shin, and foot has been shown to increase metabolic rate by 14%, 9% and 48%, respectively, above the metabolic rate required to carry 8 kg on the waist (Browning et al. 2007). It is likely that adding mass to protect the legs (such as knee and shin protectors, and combat boots) increases the moment of inertia during leg swing, requiring a greater metabolic cost to swing the legs when walking (Browning et al. 2007). To date, no studies have investigated the individual effect of police PPE for the extremities (e.g. helmets, boots, lower limb protection) on the metabolic cost of performing activities. In contrast to the rest of the police PPE literature, Marins et al. (2020b) reported no difference in VO_2 or heart rate between protective equipment (protective vest and duty belt weighing ~8–12 kg) and ordinary station wear (weighing ~1.5 kg) during a graded exercise test. The authors attributed this to the placement of the additional load, which was carried around the waist and on the upper thigh.

There appears to be a mass dependent effect of protective equipment on heat strain, with heavy protection (~20 kg) increasing body temperature and sweat rates (Zwingmann et al. 2021a), but there also appears to be no effect on these thermophysiological variables with lighter protection (~3 kg) (Pyke, Costello, and Stewart 2015, Roberts and Cole 2013), which is more representative of standard issue police uniforms. As such, certain forms of police officer, such as tactical police who tend to wear heavier protective equipment (Thomas et al. 2018, Zwingmann et al. 2021a), are more susceptible to heat strain and might benefit from the development of body armour systems that include air induction systems, which have been shown to slightly reduce the rate that core body temperature increases when exercising in hot environments with body armour (Ryan et al. 2014).

Occupational task performance, biomechanics and mobility

A wide range of activities have been investigated to assess occupational task performance with PPE (Table 2). This is indicative of the wide range of roles and activities that police officers are required to perform, from victim drags and chasing suspects (Schram et al. 2018b, Marins et al. 2020b), to stair climbing (Lowe et al. 2016) and marksmanship (Thomas et al. 2018, Schram et al. 2018b). Overall, wearing protective equipment has been shown to reduce functional performance (Marins et al. 2020a, Zedler and Goldmann 2022) and mobility (Dempsey, Handcock, and Rehrer 2013, Blackledge et al. 2009, Larsen, Tranberg, and Ramstrand 2016) compared to not wearing any protection, but this appears to be dependent on the mass of the additional external load for some tasks, with little difference in the performance of jumping and linear sprinting activities between different types of protective equipment that differ in mass up to 4 kg (Orr, Schram, and Pope 2018, Schram et al. 2018b). As such, wearing armour with increased protection (e.g. bullet-resistant vest vs. stab resistant vest), which is usually heavier, might not have a negative impact on these activities. However, increasing body armour mass by ~4 kg has been shown to reduce performance in agility tests (Orr et al. 2019), which is in line with previous research demonstrating a reduction in agility with an increase in load carriage mass across tactical occupations (military and fire service) (Joseph et al. 2018).

Few studies have investigated the kinematics and kinetics associated with police officer specific protective equipment. Dempsey, Handcock, and Rehrer (2014) are the only authors to report the associated ground reaction forces (GRF) and found increases of 13–19% peak GRF when jumping vertically with stab resistant body armour and a duty belt (total mass = 7.65 ± 0.73 kg). This is in line with other load carriage literature that has shown GRF's increasing in proportion to the mass of the added external load (Kinoshita 1985, Birrell, Hooper, and Haslam 2007, Lloyd and Cooke 2000a). The increase in GRF is accompanied by in an increase in pressure under the feet (Kasović et al. 2020). Police officer PPE has also been shown to increase pressure on the areas of the body where the equipment is worn, with increased pressure on the lower back when wearing a duty belt, which moves to the upper back region when duty belts are replaced with load bearing vests (Larsen, Ramstrand, and Tranberg 2019). It is possible that the increased pressure is linked to the pain and discomfort that has been reported in these regions when wearing a duty belt or load bearing vest (Dempsey, Handcock, and Rehrer 2014, Ramstrand et al. 2016), although a link between pressure and discomfort has not been investigated for police PPE.

The effect of carrying external load on walking gait stride parameters has been extensively studied (e.g. Kinoshita 1985, Martin and Nelson 1986, Lafiandra et al. 2003, Lloyd and Cooke 2011, Silder, Delp, and Besier 2013, Middleton et al. 2022, Huang and Kuo 2014) and while the results of these studies have varied, likely due to difference in methodological design (e.g. walking speed, load mass, load placement), most have found no change in stride length or frequency (Middleton et al. 2022, Huang and Kuo 2014, Silder, Delp, and Besier 2013, Wood and Orloff 2007, Kinoshita 1985, Lloyd and Cooke 2011). The studies that have reported changes in gait stride parameters have found a shortening of stride length walking with heavy loads (40% body mass) compared to unloaded walking (Lafiandra et al. 2003) or used fast walking speeds (6.4 km/h) when comparing loaded walking to unloaded walking (Martin and Nelson 1986). Studies on police PPE appear to align with this wider load carriage literature with some studies reporting no difference in spatio-temporal variables (Larsen, Tranberg, and Ramstrand 2016, Ramstrand et al. 2016) and the authors suggesting that the mass of load carriage borne by police officers (6–7 kg) might not enough be to induce changes to walking gait stride patterns (Ramstrand et al. 2016). However, this is not a unanimous finding with Kasović et al. (2020) reporting reduced stride length, cadence and walking speed, and increased stride time and step width with PPE weighing ~3.5 kg. The participants in the Kasović et al. (2020) study increased walking speed between conditions, but the speeds were not different between conditions in Ramstrand et al. (2016) and Larsen, Tranberg, and Ramstrand (2016), which might account for the different stride patterns reported between the studies.

Although changes in stride patterns have been infrequently reported, body armour and duty belts do appear to alter the walking gait through reduced trunk range of motion and increase ankle joint moments (Larsen, Tranberg, and Ramstrand 2016). However, these gait changes to the motion of the trunk PPE might be reduced after a period of habituation (Ramstrand et al. 2016). This suggests a potential training effect in walking gait mechanics with load carriage, which has also been demonstrated in the wider load carriage literature (Wills et al. 2019). The effects of PPE on the walking gait of police officers have only been assessed over short distances, and there has been no research on the running gait mechanics or the impact of fatigue on running mechanics for officers with PPE. This is surprising given that 11 studies included some form of running/sprinting protocol to assess occupational performance (Table 2). Understanding the interaction between PPE and the body, and potential mechanism for reduced performance could help to inform the design of future PPE.

Studies including measures of postural sway, balance, or functional movement (including range of motion) have suggested that police officer PPE can increase postural sway during balance tasks (indicating reduced balance) (Orr, Schram, and Pope 2018) and reduce joint specific range of motion (Blackledge et al. 2009). Balance and mobility in police PPE appear to be further impaired by fatigue, with Dempsey, Handcock, and Rehrer (2013) demonstrated reduced mobility task performance in timed balance, grapple and agility tasks of 6–16% with police PPE (mass = ~7 kg) compared to exercise clothing. Blackledge et al. (2009) and Orr, Schram, and Pope (2018) both demonstrated that the type of body armour also plays a role in functional movement screen scores and movement restrictions, with external body armour restricting joints movements more than soft concealable body armour (Blackledge et al. 2009) and military body armour performing worse in functional movement screen tests compared to police PPE (Orr, Schram, and Pope 2018).

Comfort and subjective perceptions

Subjective perceptions are one of the most studied areas of police PPE, with several studies including measures of perceived exertion during exercise (e.g. Dempsey, Handcock, and Rehrer 2013, Dempsey, Handcock, and Rehrer 2014, Divencenzo et al. 2014, Ehnes et al. 2020) and several studies exploring fit and comfort (e.g. Divencenzo et al. 2014, Larsen et al. 2018, Malbon et al. 2020, Ramstrand et al. 2016). As might be expected, RPE has been shown to increase with the addition of external load from PPE (Table 4), which is in line with findings from the wider load carriage research (Gordon et al. 1983). RPE is a measure of perceived whole-body exertion, which is useful for providing an overall measure of perceived effort, but does not provide detail of the perceived local effects of body armour at specific body locations. As such, studies exploring comfort and fit have mostly used visual analogue scales to provide body region specific measures (Divencenzo et al. 2014, Larsen et al. 2018, Ramstrand et al. 2016). These studies have tended to suggest that police PPE increases pain and discomfort in the region of the body it is being worn. For body armour vests, which cover the torso, female officers have reported rubbing and discomfort around the breast area (Malbon et al. 2020, Malbon et al. 2022, Niemczyk, Arnold, and Wang 2020) and both males and females have reported discomfort in the upper back (Ramstrand et al. 2016). Wearing sports bras has been shown to reduce the discomfort of body armour for female officers (Malbon et al. 2022), although Niemczyk, Arnold, and Wang (2020) suggested that female officers report the compression caused by sports bras to be unbearable after a couple of hours, particularly for females with larger bra sizes. While it might be expected that adding an external mass to an area of the body leads to increased discomfort and pain in that region, it highlights that further work is needed to try and reduce discomfort and pain with police PPE, particularly for female officers. One method of achieving this could be through improved fit, with Niemczyk, Arnold, and Wang (2020) and Malbon et al. (2022) demonstrating that female police officers are subject to greater discomfort with poorly fitted protective equipment. Indeed, ill-fitting body armour has been linked to musculoskeletal pain and discomfort in military populations (Coltman et al. 2020) and has also been linked to reduced functional performance in aerospace, military, healthcare, and firefighter populations (Brisbine et al. 2022).

A few studies have also reported thermal comfort and thermal sensation as subjective measures of thermal stress when wearing police specific PPE (Pyke, Costello, and Stewart 2015, Ryan et al. 2014). These studies reported no significant difference in thermal comfort and sensation when exercising for 60–120 minutes in hot and humid environments with light body armour (~3 kg). This is in line with measures of core body temperature, which appears to be unaffected when exercising in hot and humid environments with light protection (~3 kg) compared to no PPE conditions (Pyke, Costello, and Stewart 2015, Roberts and Cole 2013). However, wearing police specific body armour in hot and humid environments during an eight-hour working day has been shown to result in self-reported symptoms of mild-moderate heat illness such as thirst, feeling tired, dizziness and muscle weakness (Stewart and Hunt 2011). As core body temperature and sweat rates have been shown to increase with police PPE weighing ~20kg (Zwingmann et al. 2021a), it is likely that heavier police PPE, such as that worn by riot police or tactical police officers, will lead to increased thermal discomfort.

Areas for future research

There is no research on the comfort and functionality of police PPE in specialist areas such as dog support units and mounted sections. These could be important areas for future research given the impact that police PPE has on reduced comfort (e.g. Larsen et al. 2018) and reduced functional performance during simple movements such as running (e.g. Lewinski et al. 2015) and jumping (e.g. Dempsey, Handcock, and Rehrer 2014). This is further highlighted by research showing differences in the common injuries associated with different police officer roles, with the most common injury mechanisms for Mounted police reported to be falls from height (15.9% of injuries) and repetitive tasks/movements (10.6% of injuries), whereas non-mounted police most frequently reported injuries from physical assault (21.3% of injuries)(Orr et al. 2023). Orr et al. (2023) also found differences in the most frequently reported body sites for injury, with lower back (13.9%), neck (7.3%) and shoulder (7.3%) injuries most common for mounted police officer, and knee (13.9%), lower back (10%) and hand (8.2%) most common for non-mounted police officers.

Poorly fitting PPE has been shown to negatively impact functional performance across several occupational domains (Brisbine et al. 2022), but no studies appear to have investigated this in the police. This might be a serious omission from the current body of literature given the lack of fit and poor comfort that has been reported for female officers (Malbon et al. 2020). Further work is clearly needed to develop body armour vests that have greater alterability to provide improved comfort for a wide variety of body shapes, and to understand the impact that the fit of police specific PPE could have on the performance of policing activities. An important consideration for this future research is to recruit a diverse sample that adequately accounts for variability in anthropometry and posture across male and female police officers. This approach to participant sampling was identified by Brisbine et al. (2022) in their review of PPE across several occupational domains (military, firefighter, aerospace, healthcare and manufacturing), and it is an important consideration for future research on police PPE, particularly where there is scope for individual differences in accompanying garments, such as bra type (Niemczyk, Arnold, and Wang 2020). It should be noted by future researchers that, whilst is useful to understand potential reductions to occupational performance and discomfort caused by protective equipment, it is also important to consider the risk of overmatching injury when considering the balance between protection and performance, particularly for ballistic threats (Mabbott and Carr 2020).

Limitations

Protective equipment used in chemical, biological, radiological, and nuclear (CBRN) incident environments was not included in this review due the differing nature of this equipment compared to standard police PPE. For example, CBRN PPE requires a fully encapsulating impermeable protection with breathing apparatus (Richmond et al. 2013). This could be considered a limitation of this review as functionality and comfort with CBRN equipment is likely to be reduced compared to standard PPE, particularly as it has been shown to result in extreme core body temperatures (39.2 ± 0.3 °C) during house entry tasks (Blacker et al. 2013).

Conclusion

Most studies investigating the comfort and functional performance of police officer PPE have been in the areas of subjective perceptions of exertion and comfort, occupational task performance, physiological and thermophysiological responses, and biomechanics and mobility. Based on the available evidence police officer PPE appears to: (1) increase discomfort and perceived exertion during exercise, with particular focus on female discomfort; (2) increase heart rate and metabolic energy expenditure during exercise, with the effects increasing as the mass of the protection is increased; (3) decrease jumping, sprinting and agility performance with heavy PPE, but marksmanship appears unaffected; (4) reduce joint specific ROM, with the design and location of the PPE having a larger impact on movement restriction than the mass of the equipment. The literature is mostly focused on standard and tactical policing and there is a lack of evidence on the functionality of PPE for specialist units such as dog handling, mounted and marine policing. Further research is also needed on the effect that the fit of police specific PPE can have on functional performance across different types of police activity, which might be an important factor for police performance given that poorly fitted body armour has been shown to have a negative effect on occupational performance for military personnel, firefighters and individuals working in the aerospace industry.

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References

Abramov, I., N. Moiseyev, and A. Stoklitsky. 2001. “Concept of Space Suit Enclosure for Planetary Exploration.” In *31 International Conference on Environmental Systems*, Orlando, Florida, USA. SAE Technical Paper.

Armstrong, N. C., A. Ward, M. Lomax, M. J. Tipton, and J. R. House. 2019. “Wearing Body Armour and Backpack Loads Increase the Likelihood of Expiratory Flow Limitation and Respiratory Muscle Fatigue during Marching.” *Ergonomics* 62 (9): 1181–1192. doi:10.1080/00140139.2019.1629638.

Birrell, S. A., R. H. Hooper, and R. A. Haslam. 2007. “The Effect of Military Load Carriage on Ground Reaction Forces.” *Gait & Posture* 26 (4): 611–614. doi:10.1016/j.gaitpost.2006.12.008.

Blacker, S. D., J. M. Carter, D. M. Wilkinson, V. L. Richmond, M. P. Rayson, and M. Peattie. 2013. “Physiological Responses of Police Officers during Job Simulations Wearing Chemical, Biological, Radiological and Nuclear Personal Protective Equipment.” *Ergonomics* 56 (1): 137–147. doi:10.1080/00140139.2012.734335.

Blackledge, C., D. Carruth, K. Babski-Reeves, D. Close, and M. Wilhelm. 2009. “Effects of Body Armor Design on Upper Body Range of Motion.”. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, SAGE Publications Sage CA: Los Angeles, CA, 907–911. doi:10.1177/154193120905301411.

Bonneau, J., and J. Brown. 1995. “Physical Ability, Fitness and Police Work.” *Journal of Clinical Forensic Medicine* 2 (3): 157–164. doi:10.1016/1353-1131(95)90085-3.

Brisbine, B. R., C. R. Radcliffe, M. L. Jones, L. Stirling, and C. E. Coltman. 2022. “Does the Fit of Personal Protective Equipment Affect Functional Performance? A Systematic Review across Occupational Domains.” *PloS One* 17 (11): e0278174. doi:10.1371/journal.pone.0278174.

Brown, J. 2021. *Police Powers: An Introduction*. House of Commons Library.

Browning, R. C., J. R. Modica, R. Kram, and A. Goswami. 2007. “The Effects of Adding Mass to the Legs on the Energetics and Biomechanics of Walking.” *Medicine and Science in Sports and Exercise* 39 (3): 515–525. doi:10.1249/mss.0b013e31802b3562.

Caldwell, J. N., L. Engelen, C. VAN DER Henst, M. J. Patterson, and N. A. Taylor. 2011. “The Interaction of Body Armor, Low-Intensity Exercise, and Hot-Humid Conditions on Physiological Strain and Cognitive Function.” *Military Medicine* 176 (5): 488–493. doi:10.7205/milmed-d-10-00010.

Carbone, P. D., S. D. Carlton, M. Stierli, and R. M. Orr. 2014. “The Impact of Load Carriage on the Marksmanship of the Tactical Police Officer: A Pilot Study.” *Journal of Australian Strength & Conditioning* 22: 50–57.

Chang, C.-H., M.-J. J. Wang, and S.-C. Lin. 1999. “Evaluating the Effects of Wearing Gloves and Wrist Support on Hand–Arm Response While Operating an in-Line Pneumatic Screwdriver.” *International Journal of Industrial Ergonomics* 24 (5): 473–481. doi:10.1016/S0169-8141(98)00053-5.

Choi, H. J., K. Blake Mitchell, T. Garlie, J. Mcnamara, E. Hennessy, and J. Carson. 2016. “Effects of Body Armor Fit on Marksmanship Performance.”. Advances in Physical Ergonomics and Human Factors: Proceedings of the AHFE 2016 International Conference on Physical Ergonomics and Human Factors, July 27-31, 2016, Walt Disney World®, Florida, USA, Springer, 341–354.

Coltman, C. E., J. R. Steele, W. A. Spratford, and R. H. Molloy. 2020. "Are Female Soldiers Satisfied with the Fit and Function of Body Armour?" *Applied Ergonomics* 89: 103197. doi:10.1016/j.apergo.2020.103197.

Dempsey, P. C., P. J. Handcock, and N. J. Rehrer. 2013. "Impact of Police Body Armour and Equipment on Mobility." *Applied Ergonomics* 44 (6): 957–961. doi:10.1016/j.apergo.2013.02.011.

Dempsey, P. C., P. J. Handcock, and N. J. Rehrer. 2014. "Body Armour: The Effect of Load, Exercise and Distraction on Landing Forces." *Journal of Sports Sciences* 32 (4): 301–306. doi:10.1080/02640414.2013.823226.

Divencenzo, H. R., A. L. Morgan, C. M. Laurent, and K. T. Keylock. 2014. "Metabolic Demands of Law Enforcement Personal Protective Equipment during Exercise Tasks." *Ergonomics* 57 (11): 1760–1765. doi:10.1080/00140139.2014.943682.

Ehnes, C. M., M. P. Scarlett, S. J. Lemelin, M. K. Stickland, and S. R. Petersen. 2020. "The Effect of General Duty Police Ensemble on Graded Exercise and Simulated Work Performance." *Applied Physiology, Nutrition, and Metabolism = Physiologie Appliquee, Nutrition et Metabolisme* 45 (3): 301–310. doi:10.1139/apnm-2019-0230.

Executive, H. A. S. 2023. *Personal protective equipment (PPE) at work* [Online]. Available: https://www.hse.gov.uk/ppe/index.htm [Accessed].

Fineman, R. A., T. M. Mcgrath, D. G. Kelty-Stephen, A. F. Abercromby, and L. A. Stirling. 2018. "Objective Metrics Quantifying Fit and Performance in Spacesuit Assemblies." *Aerospace Medicine and Human Performance* 89 (11): 985–995. doi:10.3357/AMHP.5123.2018.

Gordon, M., B. Goslin, T. Graham, and J. Hoare. 1983. "Comparison between Load Carriage and Grade Walking on a Treadmill." *Ergonomics* 26 (3): 289–298. doi:10.1080/00140138308963342.

Hinde, K., R. Lloyd, C. Low, and C. Cooke. 2017. "The Effect of Temperature, Gradient, and Load Carriage on Oxygen Consumption, Posture, and Gait Characteristics." *European Journal of Applied Physiology* 117 (3): 417–430. doi:10.1007/s00421-016-3531-7.

Huang, T.-W. P., and A. D. Kuo. 2014. "Mechanics and Energetics of Load Carriage during Human Walking." *The Journal of Experimental Biology* 217 (Pt 4): 605–613. doi:10.1242/jeb.091587.

Jewett, B. R., C. Tomes, K. Voigt, and G. M. Mokha. 2023. "The Effects of Equipment Carriage on Functional Movement Quality among Law Enforcement Officers." *Ergonomics*: 1–11. doi:10.1080/00140139.2023.2199954.

Joseph, A., A. Wiley, R. Orr, B. Schram, and J. J. Dawes. 2018. "The Impact of Load Carriage on Measures of Power and Agility in Tactical Occupations: A Critical Review." *International Journal of Environmental Research and Public Health* 15 (1): 88. doi:10.3390/ijerph15010088.

Kamon, E., and H. S. Belding. 1971. "The Physiological Cost of Carrying Loads in Temperate and Hot Environments." *Human Factors* 13 (2): 153–161. doi:10.1177/001872087101300207.

Kasović, M., L. Štefan, K. Borovec, M. Zvonař, and J. Cacek. 2020. "Effects of Carrying Police Equipment on Spatiotemporal and Kinetic Gait Parameters in First Year Police Officers." *International Journal of Environmental Research and Public Health* 17 (16): 5750. doi:10.3390/ijerph17165750.

Kinoshita, H. 1985. "Effects of Different Loads and Carrying Systems on Selected Biomechanical Parameters Describing Walking Gait." *Ergonomics* 28 (9): 1347–1362. doi:10.1080/00140138508963251.

Knapik, J. J., P. Ang, H. Meiselman, W. Johnson, J. Kirk, C. Bensel, and W. Hanlon. 1997. "Soldier Performance and Strenuous Road Marching: influence of Load Mass and Load Distribution." *Military Medicine* 162 (1): 62–67.

Lafiandra, M., R. C. Wagenaar, K. Holt, and J. Obusek. 2003. "How Do Load Carriage and Walking Speed Influence Trunk Coordination and Stride Parameters?" *Journal of Biomechanics* 36 (1): 87–95. doi:10.1016/s0021-9290(02)00243-9.

Larsen, B., K. Netto, D. Skovli, K. Vincs, S. Vu, and B. Aisbett. 2012. "Body Armor, Performance, and Physiology during Repeated High-Intensity Work Tasks." *Military Medicine* 177 (11): 1308–1315. doi:10.7205/milmed-d-11-00435.

Larsen, L. B., E. E. Andersson, R. Tranberg, and N. Ramstrand. 2018. "Multi-Site Musculoskeletal Pain in Swedish Police: associations with Discomfort from Wearing Mandatory Equipment and Prolonged Sitting." *International Archives of Occupational and Environmental Health* 91 (4): 425–433. doi:10.1007/s00420-018-1292-9.

Larsen, L. B., N. Ramstrand, and R. Tranberg. 2019. "Duty Belt or Load-Bearing Vest? Discomfort and Pressure Distribution for Police Driving Standard Fleet Vehicles." *Applied Ergonomics* 80: 146–151. doi:10.1016/j.apergo.2019.05.017.

Larsen, L. B., R. Tranberg, and N. Ramstrand. 2016. "Effects of Thigh Holster Use on Kinematics and Kinetics of Active Duty Police Officers." *Clinical Biomechanics (Bristol, Avon)* 37: 77–82. doi:10.1016/j.clinbiomech.2016.06.009.

Lenton, G., B. Aisbett, D. Neesham-Smith, A. Carvajal, and K. Netto. 2016. "The Effects of Military Body Armour on Trunk and Hip Kinematics during Performance of Manual Handling Tasks." *Ergonomics* 59 (6): 806–812. doi:10.1080/00140139.2015.1092589.

Lewinski, W. J., J. L. Dysterheft, N. D. Dicks, and R. W. Pettitt. 2015. "The Influence of Officer Equipment and Protection on Short Sprinting Performance." *Applied Ergonomics* 47: 65–71. doi:10.1016/j.apergo.2014.08.017.

Lewis, E. A., J. Breeze, C. Malbon, and D. J. Carr. 2017. *Personal Armour Used by UK Armed Forces and UK Police Forces*. *Ballistic Trauma: A Practical Guide*, 47–62

Lloyd, R., and C. Cooke. 2000a. "Kinetic Changes Associated with Load Carriage Using Two Rucksack Designs." *Ergonomics* 43 (9): 1331–1341. doi:10.1080/001401300421770.

Lloyd, R., and C. Cooke. 2000b. "The Oxygen Consumption with Unloaded Walking and Load Carriage Using Two Different Backpack Designs." *European Journal of Applied Physiology* 81 (6): 486–492. doi:10.1007/s004210050072.

Lloyd, R., and C. Cooke. 2011. "Biomechanical Differences Associated with Two Different Load Carriage Systems and Their Relationship to Economy." *Human Movement* 12 (1): 65–74. doi:10.2478/v10038-011-0006-x.

Lowe, J. B., E. M. Scudamore, S. L. Johnson, V. Pribyslavska, M. C. Stevenson-Wilcoxson, J. M. Green, and E. K. O'neal. 2016. "External Loading during Daily Living Improves High Intensity Tasks under Load." *International Journal of Industrial Ergonomics* 55: 34–39. doi:10.1016/j.ergon.2016.07.004.

Mabbott, A., and D. J. Carr. 2020. "Effects of Police Body Armour on Overmatching Ballistic Injury." *International Journal of Legal Medicine* 134 (2): 583–590. doi:10.1007/s00414-019-02070-9.

Majumdar, D., K. Srivastava, S. Purkayastha, G. Pichan, and W. Selvamurthy. 1997. "Physiological Effects of Wearing Heavy Body Armour on Male Soldiers." *International Journal of Industrial Ergonomics* 20 (2): 155–161. doi:10.1016/S0169-8141(96)00057-1.

Malbon, C., C. Knock, R. Critchley, and D. J. Carr. 2020. "The Effect of Breast Size and Bra Type on Comfort for UK Female Police Officers Wearing Body Armour." *Applied Ergonomics* 84: 103012. doi:10.1016/j.apergo.2019.103012.

Malbon, C., C. Knock, R. Critchley, and D. J. Carr. 2022. "The Effect of Underwired and Sports Bras on Breast Shape, Key Anthropometric Dimensions, and Body Armour Comfort." *The Police Journal: Theory, Practice and Principles* 95 (3): 436–458. doi:10.1177/0032258X211011619.

Marins, E. F., L. Cabistany, C. Bartel, J. Dawes, and F. B. DEL Vecchio. 2020a. "Effects of Personal Protective Equipment on the Performance of Federal Highway Policemen in Physical Fitness Tests." *Journal of Strength and Conditioning Research* 34 (1): 11–19. doi:10.1519/JSC.0000000000003201.

Marins, E. F., L. Cabistany, C. Farias, J. Dawes, and F. B. DEL Vecchio. 2020b. "Effects of Personal Protective Equipment on Metabolism and Performance during an Occupational Physical Ability Test for Federal Highway Police Officers." *Journal of Strength and Conditioning Research* 34 (4): 1093–1102. doi:10.1519/JSC.0000000000002892.

Martin, P. E., and R. C. Nelson. 1986. "The Effect of Carried Loads on the Walking Patterns of Men and Women." *Ergonomics* 29 (10): 1191–1202. doi:10.1080/00140138608967234.

Middleton, K., D. Vickery-Howe, B. Dascombe, A. Clarke, J. Wheat, J. Mcclelland, and J. Drain. 2022. "Mechanical Differences between Men and Women during Overground Load Carriage at Self-Selected Walking Speeds." *International Journal of Environmental Research and Public Health* 19 (7): 3927. doi:10.3390/ijerph19073927.

Niemczyk, S. E., L. Arnold, and L. Wang. 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. doi:10.1080/17543266.2020.1758800.

Orr, R., E. F. Canetti, R. Pope, R. G. Lockie, J. J. Dawes, and B. Schram. 2023. "Characterization of Injuries Suffered by Mounted and Non-Mounted Police Officers." *International Journal of Environmental Research and Public Health* 20 (2): 1144. doi:10.3390/ijerph20021144.

Orr, R., B. Hinton, A. Wilson, R. Pope, and J. Dawes. 2020. "Investigating the Routine Dispatch Tasks Performed by Police Officers." *Safety* 6 (4): 54. doi:10.3390/safety6040054.

Orr, R., B. Schram, and R. Pope. 2018. "A Comparison of Military and Law Enforcement Body Armour." *International Journal of Environmental Research and Public Health* 15 (2): 339. doi:10.3390/ijerph15020339.

Orr, R. M., F. Kukić, A. Čvorović, N. Koropanovski, R. Janković, J. Dawes, and R. Lockie. 2019. "Associations between Fitness Measures and Change of Direction Speeds with and without Occupational Loads in Female Police Officers." *International Journal of Environmental Research and Public Health* 16 (11): 1947. doi:10.3390/ijerph16111947.

Park, J., and K. Langseth-Schmidt. 2016. "Anthropometric Fit Evaluation of Firefighters' Uniform Pants: A Sex Comparison." *International Journal of Industrial Ergonomics* 56: 1–8. doi:10.1016/j.ergon.2016.08.011.

Phillips, M., B. Bazrgari, and R. Shapiro. 2015. "The Effects of Military Body Armour on the Lower Back and Knee Mechanics during Toe-Touch and Two-Legged Squat Tasks." *Ergonomics* 58 (3): 492–503. doi:10.1080/00140139.2014.970589.

Phillips, M. P., R. Shapiro, and B. Bazrgari. 2016. "The Effects of Military Body Armour on the Lower Back and Knee Mechanics during Box Drop and Prone to Standing Tasks." *Ergonomics* 59 (5): 682–691. doi:10.1080/00140139.2015.1081413.

Pyke, A. J., J. T. Costello, and I. B. Stewart. 2015. "Heat Strain Evaluation of Overt and Covert Body Armour in a Hot and Humid Environment." *Applied Ergonomics* 47: 11–15. doi:10.1016/j.apergo.2014.08.016.

Quesada, P. M., L. J. Mengelkoch, R. C. Hale, and S. R. Simon. 2000. "Biomechanical and Metabolic Effects of Varying Backpack Loading on Simulated Marching." *Ergonomics* 43 (3): 293–309. doi:10.1080/001401300184413.

Ramstrand, N., R. Zügner, L. B. Larsen, and R. Tranberg. 2016. "Evaluation of Load Carriage Systems Used by Active Duty Police Officers: relative Effects on Walking Patterns and Perceived Comfort." *Applied Ergonomics* 53 Pt A: 36–43. doi:10.1016/j.apergo.2015.08.007.

Ricciardi, R., P. A. Deuster, and L. A. Talbot. 2007. "Effects of Gender and Body Adiposity on Physiological Responses to Physical Work While Wearing Body Armor." *Military Medicine* 172 (7): 743–748. doi:10.7205/milmed.172.7.743.

Richmond, V., D. Wilkinson, S. Blacker, F. Horner, J. Carter, G. Havenith, and M. Rayson. 2013. "Insulated Skin Temperature as a Measure of Core Body Temperature for Individuals Wearing CBRN Protective Clothing." *Physiological Measurement* 34 (11): 1531–1543. doi:10.1088/0967-3334/34/11/1531.

Roberts, A. P., and J. C. Cole. 2013. "The Effects of Exercise and Body Armor on Cognitive Function in Healthy Volunteers." *Military Medicine* 178 (5): 479–486. doi:10.7205/MILMED-D-12-00385.

Ryan, G. A., S. H. Bishop, R. L. Herron, C. P. Katica, B. A. L. Elbon, A. M. Bosak, and P. Bishop. 2014. "Ambient Air Cooling for Concealed Soft Body Armor in a Hot Environment." *Journal of Occupational and Environmental Hygiene* 11 (2): 93–100. doi:10.1080/15459624.2013.843782.

Schram, B., B. Hinton, R. Orr, R. Pope, and G. Norris. 2018a. "The Perceived Effects and Comfort of Various Body Armour Systems on Police Officers While Performing Occupational Tasks." *Annals of Occupational and Environmental Medicine* 30 (1): 15. doi:10.1186/s40557-018-0228-x.

Schram, B., R. Orr, B. Hinton, G. Norris, and R. Pope. 2020. "The Effects of Body Armour on Mobility and Postural Control of Police Officers." *Journal of Bodywork and Movement Therapies* 24 (3): 190–194. doi:10.1016/j.jbmt.2020.03.001.

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

Schram, B., R. Orr, R. Pope, B. Hinton, and G. Norris. 2018b. "Comparing the Effects of Different Body Armor Systems on the Occupational Performance of Police Officers." *International Journal of Environmental Research and Public Health* 15 (5): 893. doi:10.3390/ijerph15050893.

Silder, A., S. L. Delp, and T. Besier. 2013. "Men and Women Adopt Similar Walking Mechanics and Muscle Activation

Patterns during Load Carriage." *Journal of Biomechanics* 46 (14): 2522–2528. doi:10.1016/j.jbiomech.2013.06.020.

Simpson, K. M., B. J. Munro, and J. R. Steele. 2011. "Effect of Load Mass on Posture, Heart Rate and Subjective Responses of Recreational Female Hikers to Prolonged Load Carriage." *Applied Ergonomics* 42 (3): 403–410. doi:10.1016/j.apergo.2010.08.018.

Soule, R. G., and R. F. Goldman. 1969. "Energy Cost of Loads Carried on the Head, Hands, or Feet." *Journal of Applied Physiology* 27 (5): 687–690. doi:10.1152/jappl.1969.27.5.687.

Stewart, I. B., and A. P. Hunt. 2011. "Negligible Heat Strain in Armored Vehicle Officers Wearing Personal Body Armor." *Journal of Occupational Medicine and Toxicology* 6 (1): 22. doi:10.1186/1745-6673-6-22.

Thomas, M., M. B. Pohl, R. Shapiro, J. Keeler, and M. G. Abel. 2018. "Effect of Load Carriage on Tactical Performance in Special Weapons and Tactics Operators." *Journal of Strength and Conditioning Research* 32 (2): 554–564. doi:10.1519/JSC.0000000000002323.

Tomes, C., R. M. Orr, and R. Pope. 2017. "The Impact of Body Armor on Physical Performance of Law Enforcement Personnel: A Systematic Review." *Annals of Occupational and Environmental Medicine* 29 (1): 14. doi:10.1186/s40557-017-0169-9.

Tricco, Andrea C., Erin Lillie, Wasifa Zarin, Kelly K. O'Brien, Heather Colquhoun, Danielle Levac, David Moher, Micah D J. Peters, Tanya Horsley, Laura Weeks, Susanne Hempel, Elie A. Akl, Christine Chang, Jessie McGowan, Lesley Stewart, Lisa Hartling, Adrian Aldcroft, Michael G. Wilson, Chantelle Garritty, Simon Lewin, Christina M. Godfrey, Marilyn T. Macdonald, Etienne V. Langlois, Karla Soares-Weiser, Jo Moriarty, Tammy Clifford, Özge Tunçalp, and Sharon E. Straus. 2018. "PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation." *Annals of Internal Medicine* 169 (7): 467–473. doi:10.7326/M18-0850.

Wills, J. A., D. J. Saxby, G. K. Lenton, and T. L. Doyle. 2019. "Ankle and Knee Moment and Power Adaptations Are Elicited through Load Carriage Conditioning in Males." *Journal of Biomechanics* 97: 109341. doi:10.1016/j.jbiomech.2019.109341.

Wood, W., and H. Orloff. 2007. "Comparison of Two Backpack Designs Using Biomechanical and Metabolic Aspects of Load Carriage." *ISBS-Conference Proceedings Archive.* XXV ISBS Symposium, Ouro Preto, Brazil.

Zedler, M., and J.-P. Goldmann. 2022. "Police-Specific Physical Performance of Men and Women with Different Body Heights." *The Police Journal: Theory, Practice and Principles* 1–15. doi:10.1177/0032258X221126066.

Zwingmann, L., T. Below, H. Braun, P. Wahl, and J.-P. Goldmann. 2021a. "Consequences of Police-Related Personal Protective Equipment and Physical Training Status on Thermoregulation and Exercise Energy Expenditure." *The Journal of Sports Medicine and Physical Fitness* 62 (9): 1137–1146. doi:10.23736/S0022-4707.21.12196-6.

Zwingmann, L., M. Hoppstock, J.-P. Goldmann, and P. Wahl. 2021b. "The Effect of Physical Training Modality on Exercise Performance with Police-Related Personal Protective Equipment." *Applied Ergonomics* 93: 103371. doi:10.1016/j.apergo.2021.103371.