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Prevention and Rehabilitation

The effects of body armour on mobility and postural control of police officers

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ABSTRACT

Background: Police officer use of Individual Light Armour Vests (ILAVs) is increasing due to potential occupational hazards that include blunt trauma, stabbing, and light calibre bullets. It is unclear how addition of this extra load will affect the officer's mobility or postural control.

Objectives: The aim of this study was to determine the effects of various ILAVs on the mobility and postural control of police officers when compared to wearing their normal station wear.

Methods: A prospective, within-subjects, repeated measures study was conducted in which officers wore one of three different ILAV variants or normal station wear (N) and acted as their own controls. Officer mobility was assessed via the Functional Movement Screen (FMS) and postural sway (including total sway, average sway velocity, medial-lateral velocity, anterior-posterior velocity, and total excursion area) via force plate.

Results: Significant differences were found between ILAV or N conditions in various components of the FMS, including right Straight Leg Raise, left shoulder mobility, and both right and left quad rotary stability. No significant differences were found in any of the balance measures between these conditions.

Conclusion: It appears ILAVs can significantly affect police officer mobility and therefore may contribute to injury risk and decreased ability to complete occupational tasks, though this should be weighed against protective benefits. ILAVs should therefore be carefully selected to minimise injury risk without detracting from occupational performance.

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1. Introduction

Occupational hazards in policing have led to an increase in the utilisation of body armour to protect officers from a variety of threats that they may face on a day to day basis (Dempsey et al., 2013; Tomes et al., 2017). Body armour is more commonly being introduced to police forces to provide a degree of protection from stabbing, blunt trauma, and light calibre bullets (Dempsey et al., 2013). Any extra addition of load to an officer may cumulatively add to what these officers are already expected to carry with research suggesting a daily typical load of up to 10 kg (Baran et al., 2018). The addition of the extra load imparted by ILAV wear may

lead to a reduction in mobility, reduce officer ability to complete occupational tasks, and may also contribute to an increase in injury risk (Dempsey et al., 2013; Orr et al., 2013, 2015).

In previous research, wearing of body armour (7.65 ± 0.73 kg) was found to significantly increase the amount of time personnel were off balance during a task which required participants to actively compensate for lateral perturbations (Dempsey et al., 2013). This compromising of their ability to respond to postural challenges may increase the risk of slips, trips, and falls, a leading mechanism of injury amongst defence personnel (Prigg et al., 2011).

Wearing body armour has also been found to compromise trunk posture (Phillips et al., 2016) and reduce range of motion in multiple planes (Lenton et al., 2016). Axial trunk rotation has been shown to be reduced by up to 12° when wearing military-styled body armour (Lenton et al., 2016). A generalized increase in trunk and hip forward flexion during tasks has also been associated with wearing body armour (Lenton et al., 2016; Phillips et al., 2015). The

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effects of both a forward trunk posture and any compromise in trunk or shoulder mobility may further affect an officer's ability to compensate for any balance compromise and put them at greater risk of falls and subsequent injury (Dempsey et al., 2013).

Before the widespread recommendation of any type of protective equipment for police officers is given, an understanding of the effects on the wearer is essential, as is an understanding of whether these effects would differ with different types of body armour. Given that both postural control and mobility can directly influence the potential risk for an officer to slip, trip or fall the postural and mobility impacts of adding body armour loads to police officer's typical load carriage requirements require investigation. Therefore, the aim of this investigation was to determine the effects of various body armour systems on the mobility and postural control of police officers when compared to wearing their normal station wear and to compare the effects of several different body armour types.

2. Materials and methods

A prospective, within-subjects, repeated measures study was conducted, employing a counterbalanced randomization protocol where each officer was allocated to wear one of four load condition types, either: ILAV A, B, or C and 'normal' (N) station wear. Each ILAV type (A, B, and C) was produced by a different company for a designated law enforcement purpose while N was the current everyday station wear of the participating officers. The nature of the study design meant that each officer acted as their own control. After being randomly allocated to one of the four conditions on the first day of data collection officers progressed to the next type of load condition following the order A, B, C, and N, and wore that load condition for the entire day. This allocation approach was used to negate any possibility of a learning effect and to control for any external factors such as varying weather conditions over the course of the study.

The data collection took place at a state police facility over a 4-day period. The ambient temperature and relative humidity across the testing periods ranged from 12 to 24 °C and from 36 to 93%, respectively, giving a heat stress index varying between 11.4 and 22.6 °C while testing occurred.

In order to obtain a sample which was representative of the general state police population, two small, medium, and larger stature male and female serving police officers were recruited. This recruitment process was aimed at enabling translation of this research to the police force as a whole, in order to understand the effects of the ILAVs across a range of body sizes from both sexes. After initially being briefed about the study, each officer expressed their willingness to participate and provided consent via a written consent form. At the beginning of the study, a female officer was removed due to medical concerns and the study sample was thereby reduced to 11 officers. The final sample thus comprised of five females (mean \pm SD age = 27 \pm 3 years; weight = 68 \pm 18 kg; height = 164 \pm 7 cm; months of service = 78 \pm 12 months) and six males (mean \pm SD age = 40 \pm 8 years; weight = 83 \pm 20 kg; height = 177 \pm 9.0 cm; months of service = 92 \pm 9 months).

This study was approved by the University Human Research Ethics Committee (protocol number 15803). To minimise the effects of diurnal variation, the same testing procedure was used each day. The data presented in this paper were drawn from a larger program of research. On this basis, the daily sequence of events (Table 1) indicates only those measures and tests that were relevant to this study.

2.1. ILAV weights

The weight of each individual ILAV was measured to the nearest 0.01 kg (Tanita, BF679W, Illinois, USA) then re-weighed once all of the officer's standard appointments were added.

Table 1
The daily sequence of events.

Time	Measure
0800	Equipment preparation and briefing
1000	Postural Sway (am)
1300	Postural Sway (pm)
1530	Functional Movement Screen
1700	Debrief

2.2. Postural sway

To assess postural sway, officers were asked to stand with their feet together in the middle of a force plate (Fitness Technology Force Plate Ballistic Measurement System) with their eyes open. Instructions were given for the officers to look straight ahead and stand as still as possible for 10 s. Data were collected using Inner-Balance (Innervations Pty Ltd) software and included measures of total sway (degrees), average sway velocity (degrees per second), and Medio-Lateral (ML) and Anterior-Posterior (AP) velocity (metres per second) and total excursion area (cm²).

2.3. Functional Movement Screen

The Functional Movement Screen (FMS) assesses seven movement patterns that include an overhead squat (or deep squat), hurdle step, in line lunge, shoulder mobility, active straight leg raise, push-up, and rotary stability (Cook et al., 2006). Each component of the FMS was scored on a scale of zero to three points. A score of zero was assigned if the officer experienced pain with any portion of the movement pattern. A score of one identified that the officer did not experience pain but could not complete the movement pattern as instructed, while a score of two identified that the officer could complete the movement pattern pain-free but required some level of compensatory movement. A score of three identified that the officer's movement pattern was completed as instructed, with no movement compensation noted and with the movement being pain-free (Cook et al., 2006). Where, scores for left and right sides differed, the lowest scores were taken as the final score. The total FMS score was calculated by summing the scores of individual elements of the FMS and could range from zero to a maximum total score of 21 (Cook et al., 2006).

All FMS assessments were conducted by qualified Police Physical Training Instructors (PTI) familiar with the FMS. In this study, two PTIs conducted the assessment. As the FMS has high inter-rater reliability (Teyhen et al., 2012) and intra-rater reliability (Gribble et al., 2013) potential differences in FMS assessors between assessed officers are unlikely to have significantly influenced the study results. This tool was selected due to its ability to not only analyze key movement patterns, but due to research in both tactical populations and within this police force specifically, linking the movement skills of the FMS and potential for injury (Bock et al., 2016; Orr et al., 2016b).

2.4. Data analysis

All data were captured and entered into a spreadsheet in SPSS version 23 (IBM, 2015) and cleaned for analysis. Initial descriptive analyses were then conducted to provide counts, means, standard deviations and ranges for the included variables, as relevant depending on levels of measurement. These descriptive statistics were derived for each sex and for each body armour type, where relevant, as well as for the entire sample. After the descriptive statistics were conducted, a multivariate repeated measures analyses of variance (ANOVA) was conducted to examine the effects of

body armour type on the key performance measures, with post hoc pairwise comparisons using a Bonferroni adjustment. Alpha was set at $p < .05$, *a priori*.

3. Results

3.1. ILAV weights

The weight of each ILAV type, daily load configurations and daily load configurations including the officers' body weights are shown in Table 2. The minimum mean weights varied between armour types by 0.3–0.9 kg while the maximum weights (reflecting the largest sizes) varied by 0.7–1.5 kg, indicating differences of possible individual (e.g., body size and larger ILAVs) or operational (e.g., personal preferences in equipment carried) significance. There were significant differences between mean weights of the three ILAV types ($p < .05$ for all on Bonferroni post-hoc tests; Table 2). The differences in ILAV weights were mitigated to some degree when the officers were fully equipped with daily work equipment (e.g. handcuffs, radio, etc) (see Table 2), however with all ILAV types, total loads carried were all still significantly heavier than normal station wear alone ($p < .002$ for all on Bonferroni post-hoc tests).

3.2. Balance

The results of the balance task are shown in Table 3. There were no significant differences in any of the balance measures between any of the ILAV or N load conditions at any time of day ($p < .05$), though there was a consistent trend for balance to be poorer in the ILAV conditions than in the N condition (Table 3). Sway velocity was greatest with ILAV C, as was the total excursion area. Both ILAV B and C were associated with the greatest mean ML and AP distance (0.085m); ILAV C with the greatest ML average velocity (0.0086 m/s) and ILAV B with the greatest AP average velocity (0.0136 m/s). The greatest change in total sway between the morning and afternoon assessments was seen in ILAV C while ILAV B was associated with the greatest change in total excursion area, across these time points.

The results for the FMS are seen in Table 4 below. Significant differences between ILAV and N conditions in FMS performance were observed within the following items of the FMS: Active SLR – Right ($F[3,30] = 4.323$, $p = .012$), Shoulder Mobility – Left ($F[3,30] = 3.095$, $p = .042$), Quad Rotary Stability – Left ($F[3,30] = 5.566$, $p = .004$), and Quad Rotary Stability – Right ($F[3,30] = 9.800$, $p < .001$). Performance on other FMS items was not affected significantly by ILAV or N condition and the effect of ILAV or N conditions on FMS total scores did not reach statistical significance ($F[3,30] = 2.170$, $p = .112$).

4. Discussion

The aim of this study was to determine the effects of a variety of ILAVs on the mobility and postural control of police officers when compared to normal station wear and to investigate any differences

between ILAV types. Overall it can be seen that there were significant differences found between load conditions in some of the mobility tasks of the FMS although there was minimal effect of the ILAV load conditions on any of the balance measures.

A notable impact of wearing the ILAV on movement ability was found in various components of the FMS. The average total FMS score for the officers in normal station wear was 12.64 (± 2.16) points (See Table 4). Not only is this score below the general FMS mean score of previously reported state police populations (14.57 ± 2.96 points (Orr et al., 2016a)), this score is also below the score of 14 which is associated with an increased risk of injury in the general, sporting, and tactical communities (Bock and Orr, 2015). Furthermore, although the change did not reach statistical significance, the wearing of ILAVs further decreased the mean total FMS score by between 0.5 (ILAV A) and 1.1 (ILAV C) points (Table 4).

Of most concern was the significantly lower scores in the left and right quad rotary stability components in all ILAV conditions when compared to normal station wear. This concern is based on state police populations already performing poorly in trunk rotary stability (Orr et al., 2016a), the lower back being a leading site of injury in other (Holmes et al., 2013; McKinnon et al., 2012) and this specific police service (Orr and Stierli, 2013), and the fact that body armour is associated with increasing the risk of lower back injuries (Roy et al., 2012).

Likewise, this study identified shoulder mobility to be significantly and negatively affected by all three types of ILAV. As with rotary stability, this reduction of shoulder mobility is of concern given that this population is already known to exhibit poor performance in this measure (males most notably) even without body armour and this poorer performance may be associated with an increased risk of shoulder injuries in this population (Bock et al., 2016). This injury risk is supported by the review of Lyons et al. (2017) who found that the upper extremity was a leading site of injuries in police officers. Therefore, it would be prudent to ensure a trunk and shoulder mobility training program is provided to help mitigate potential injuries to these bodily sites, particularly when body armour is to be worn.

As highlighted above, the mean total FMS scores listed in Table 4, particularly those associated with wearing ILAV, are low when compared to both the average for state police (Orr et al., 2016a) and also to the score associated with an increased risk of injury (Bock and Orr, 2015). These findings should highlight the necessity of individualized interventions to minimise any impact of wearing ILAV and also to reduce injury risk. Previous research has shown improvements in FMS scores can be achieved with six weeks of yoga (Cowen, 2010), seven weeks of individualized stretching and corrective exercise (Kiesel et al., 2011) and six weeks of individualized strength and conditioning programs (Goss et al., 2009).

Despite some research in this area showing an association between poorer FMS scores and injury (Bock and Orr, 2015), the link between FMS scores and injury risk is not strong (Kollock et al., 2019). An individual's FMS score may not therefore be predictive of injury. The results of this study do highlight the fact that these

Table 2
Mean \pm SD and ranges for each type of ILAV and stationwear (N) in all configurations.

ILAV type (A-C) & Normal station wear (N)	ILAV Weight (kg)	Duty load Complete (kg)	Total load including officer weight (kg)
A	4.12 \pm 0.65 ^a	11.53 \pm 0.77 ^b	88.03 \pm 20.49
B	3.54 \pm 0.70 ^a	11.01 \pm 1.01 ^b	87.51 \pm 20.60
C	3.24 \pm 0.48 ^a	10.77 \pm 1.16 ^b	87.27 \pm 20.66
N	NA	8.69 \pm 0.68	85.19 \pm 20.24

^a Significantly different ($p < .05$) from normal station wear.

^b Significantly different ($p < .001$) from normal station wear.

Table 3
Balance Results under each load condition. (Mean \pm SD).

Sway Measure	ILAV A (n = 11)	ILAV B (n = 11)	ILAV C (n = 11)	N (n = 11)
Balance Total Sway (deg)	5.123 \pm 0.911	5.081 \pm 0.866	5.169 \pm 0.838	4.837 \pm 0.808
Balance Average Sway Velocity (deg/sec)	0.507 \pm 0.090	0.503 \pm 0.086	0.512 \pm 0.083	0.479 \pm 0.080
Balance ML Total Distance (m)	0.079 \pm 0.016	0.085 \pm 0.019	0.085 \pm 0.013	0.079 \pm 0.011
Balance AP Total Distance (m)	0.083 \pm 0.014	0.085 \pm 0.016	0.085 \pm 0.018	0.076 \pm 0.014
Balance ML Average Velocity (m/sec)	0.0079 \pm 0.0016	0.0084 \pm 0.0019	0.0086 \pm 0.0013	0.0079 \pm 0.0012
Balance AP Average Velocity (m/sec)	0.0082 \pm 0.0014	0.0136 \pm 0.0186	0.0086 \pm 0.0018	0.0075 \pm 0.0013
Balance Total Excursion Area (sq/cm)	2.42 \pm 0.87	2.60 \pm 0.99	3.01 \pm 1.19	2.49 \pm 0.84
Balance Total Sway Change from AM to PM	0.50 \pm 1.70	0.47 \pm 1.29	0.81 \pm 1.64	0.23 \pm 1.67
Balance Total Excursion Area Change from AM to PM	0.80 \pm 1.46	1.25 \pm 1.85	0.66 \pm 1.69	-0.05 \pm 1.87

Table 4
FMS Results for each load condition (Mean \pm SD).

Measures	ILAV A (n = 11)	ILAV B (n = 11)	ILAV C (n = 11)	N (n = 11)
FMS Deep Squat (/3)	1.64 \pm 0.67	1.36 \pm 0.51	1.45 \pm 0.52	1.55 \pm 0.69
FMS Hurdle Left (/3)	1.55 \pm 0.52	1.45 \pm 0.52	1.73 \pm 0.47	1.64 \pm 0.51
FMS Hurdle Right (/3)	1.64 \pm 0.51	1.64 \pm 0.67	1.64 \pm 0.51	1.55 \pm 0.69
FMS Lunge Left (/3)	1.82 \pm 0.41	2.09 \pm 0.70	1.82 \pm 0.41	2.18 \pm 0.41
FMS Lunge Right (/3)	1.82 \pm 0.41	2.00 \pm 0.78	2.00 \pm 0.45	2.00 \pm 0.63
FMS Shoulder Mobility Left (/3)	2.18 \pm 0.87	2.18 \pm 0.60	2.36 \pm 0.67	2.36 \pm 0.81
FMS Shoulder Mobility Right (/3)	1.73 \pm 0.65	1.91 \pm 0.83	2.00 \pm 0.78	2.36 ^a \pm 0.81
FMS Active SLR Left (/3)	1.64 \pm 0.51	1.73 \pm 0.47	1.55 \pm 0.52	1.64 \pm 0.51
FMS Active SLR Right (/3)	1.91 ^a \pm 0.30	1.73 \pm 0.47	1.36 \pm 0.51	1.82 \pm 0.41
FMS Trunk Push Up (/3)	2.45 \pm 0.93	2.45 \pm 0.93	2.09 \pm 1.04	2.27 \pm 1.01
FMS Quad Rotary Stability Left (/3)	1.18 \pm 0.41	1.18 \pm 0.41	1.09 \pm 0.30	1.55 ^a \pm 0.52
FMS Quad Rotary Stability Right (/3)	1.27 \pm 0.47	1.27 \pm 0.47	1.27 \pm 0.47	1.91 ^a \pm 0.30
FMS Total Score (/21)	12.09 \pm 2.74	11.64 \pm 2.01	11.45 \pm 1.51	12.64 \pm 2.16

^a = Significantly different to the other results.

ILAVs do alter mobility at key joints however. Further research should be done in this area to investigate the relationship between reductions in joint mobility and injury risk and also decrements in occupational performance.

When wearing the different ILAV configurations, no significant changes were found in any measures of postural sway when compared to wearing normal station wear. It should be noted however, that there was a tendency for the three ILAV configurations to have higher perturbation scores (i.e., poorer balance performance) than the normal station wear condition for some aspects of balance, notably total sway, average sway velocity, and Anterior-Posterior (forward-backward) total distance swayed and sway velocity.

It is possible these findings regarding differences between ILAV and normal station wear conditions may have reached statistical significance with heavier loads, in agreement with the study by Dempsey et al. (2013) where 52 male police officers were found to spend greater total amounts of time off balance when wearing 7.65 kg loads including duty equipment and body armour when compared to an unloaded condition. These higher levels of sway and sway velocity do raise concern, as load carriage has been associated with an increased risk of slips, trips, and falls in some research. For example, Park et al. (2010) used obstacles to simulate debris faced by fire fighters. They found that loads of 9.1 kg led to 42% (10 of 24) of participants making contact, at least once, with a 30 cm obstacle while stepping over it. Considering this, it should be noted that slips, trips, and falls are within the top five injury mechanisms in this police population (The Audit Office of New South Wales, 2008). Anything that increases sway velocity may impact on recovery potential following a trip or slip and increase the risk of injury, and so body armour and total equipment loads should be carefully controlled, as one contributor to this risk. Previous research has demonstrated that other considerations which are important prior to the uptake of any body armour system is the

acceptance of the end user (Schram et al., 2018a) and the potential for any negative effects on an officers ability to complete occupational tasks (Schram et al., 2018b).

4.1. Strengths and limitations of this study

A strength of this study was that the ILAVs used were added to the current load which police officers carry, as opposed to comparing totally unloaded and loaded conditions. In addition, several different types of ILAVs were compared against each other. This enabled the findings to directly translate to the field as the load conditions replicate real world loads. The mild climate in which this study was conducted may be viewed as a limitation, as it may not be representative of all conditions in which officers may wear the ILAVs. Hotter conditions may have led to greater fatigue and may have had more of an influence on the results. While the officers selected were anthropometrically diverse in an attempt to represent the population, numbers were limited and as such the impact of some of the findings do lack so degree of strength.

Despite the observed decreases in officer mobility in key areas, the tradeoff between ensuring suitable protection for the officer and minimizing mobility deficits should be considered. For example, research with military loads has shown that slower movement, caused by increase load increases susceptibility to enemy fire (Billing et al., 2015). It may be that the protective benefits of ILAVs fully offset any adverse impacts on mobility and associated injuries. Prospective studies which monitor injuries should be performed to determine any changes in overall prevalence of serious and less serious injuries in this population, after the statewide uptake of these ILAVs.

Overall, it is apparent that wearing ILAVs can significantly affect mobility as assessed by some components of the FMS. These reductions in mobility may further contribute to the potential for injury amongst police officers. Due to these effects, body armour

should be carefully selected and ways in which armour can be optimized to minimise impact on the wearer should be explored.

Declaration of competing interest

This study was commissioned and funded by NSW Police. The authors declare no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jbmt.2020.03.001>.

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