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Common law enforcement load carriage systems have limited acute effects on postural stability and muscle activity

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Title: Common law enforcement load carriage systems have limited acute effects on postural stability and muscle activity

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Abstract

Law enforcement officers are inherently at a high risk of injury and the loads they must carry during their occupational duties further increase their injury risk. It is unknown how different methods of carrying a law enforcement officer's load influence factors related to injury risk. This study assessed the effects of common law enforcement load carriage systems on muscular activity and postural stability while standing. Twenty-four participants performed single and dual-task (i.e. concurrent performance of cognitive tasks) standing while wearing a duty belt, tactical vest, and no load. The postural stability and muscle activity were measured and effects of condition and task examined. Dual task standing decreased postural stability and increased muscular activity. The belt and vest (7.2 kg each) increased muscle activity compared to control for the right abdominals, low back, right thigh. The duty belt resulted in less muscle activity in the right abdominals but more muscle activity in the left multifidus compared to the control. The findings indicate that common law enforcement load carriage systems increase muscular activity but do not affect postural stability. However, the lack of differences between the duty belt and tactical vest did not provide clear support for one load carriage system versus the other.

Keywords: Work Performance, Risk Factors, Police

Abbreviations

LEO: Law Enforcement Officer

LC: Load carriage

MSI: Musculoskeletal injury

PS: Postural stability

COP: Center of Pressure

MA: Muscular Activity

sEMG: Surface Electromyography

PVT: Psychomotor Vigilance Test

QS: Quiet Standing

S7: Serial 7's

DC: Dual Communications

ML: Medial-Lateral

AP: Anterior-Posterior

AB: Abdominals

MF: Multifidus

RF: Rectus Femoris

BF: Biceps Femoris

1. Introduction

Law Enforcement is a physically demanding occupation with a high rate of injury.[1,2] Injury rates have been reported to be higher in law enforcement officers (LEO) than other first responders (i.e. firefighters and emergency medical technicians) with the incidence of injury ranging from 240 to 2500 per 1000 personnel per year.[3,4] A recent study indicated that 41.3% of LEOs reported multi-site musculoskeletal pain within the last three months.[5] Slips, trips, and falls have been reported as the most common mechanism of injury, accounting for 38% of injuries, in LEOs.[2] Duty belts and vests, commonly worn by LEO, induce a load carriage (LC) component to their occupational tasks which could increase slips, trips, and falls.[2,6] Loads that LEO carry with LC systems vary between 7.65 kg to 40 kg, depending on agency and job duties.[7,8] Body-worn LC has been known to induce postural instability,[9] increased muscular activation,[10,11] and cause decrements in cognitive function,[12,13] which all may be linked to injury risk injury in LEOs.[14] For example, decreases in postural stability have been correlated with increased incidence of injury in athletes.[15] Thus, LC worn by LEO could contribute to musculoskeletal injuries by reducing postural stability.

Several ergonomic aspects of body-worn LC influence changes in postural stability. First, as load magnitude increases, postural stability has been shown to decrease.[11] Load that is evenly distributed posteriorly and anteriorly may lead to fewer decrements in postural stability compared to load worn unevenly.[16] Many prior studies utilized heavy loads commonly used in Special Weapons and Tactics (SWAT) personnel, fire fighters, and military personnel. [14,17–19] Few studies have utilized a load of 7-10 kg that is more typically worn by LEOs.[6,19] It is plausible that decreased load and evenly distributed load placement could mitigate the negative effects of military type LC most commonly reported in the existing literature.[11,14] However, at present, it is unclear if differences in the load distribution between a LEO duty belt and duty vest may alter the effects on postural stability.

In addition to postural stability, body-worn LC has been shown to alter numerous biomechanical measures, such as knee extensor moments, cadence, stride length, and joint angles during gait.[10,20,21] Thus, it not surprising that body-worn LC has also been shown to increase muscular activity during gait because increased mass from the load carried would necessitate greater force production for movement to occur.[22] At present, there is limited research examining how common methods of LEO body-worn LC affects muscular activity during quiet standing,[11,23] a common task LEOs may perform for long durations during a shift.[24] One study of university students reported posterior worn back load of 15% body mass resulted in significantly altered muscle activity with >20% decreased erector spinae activity, >50% increased rectus abdominus activity, and a ~40% rectus abdominus asymmetry, with the right abdominals displaying more activity than the left.[23] In contrast, load worn evenly distributed anteriorly and posteriorly resulted in no change in muscle activity.[23] Likewise, Park et al. also concluded that LC increases muscle activity, with greater load increasing peak muscle activity of the rectus femoris to maintain balance.[11]

Furthermore, LEOs often perform cognitive tasks while on the job such as communicating with colleagues and dispatch, multitasking, decisive decision making, and reacting quickly to emergency situations.[25] Performing dual tasks, such as this, has been shown to reduce postural stability.[26,27] Current evidence supports that differences in specific demands of the cognitive tasks (i.e. stimulus recognition, response generation, problem-solving) may influence this relationship between postural stability and cognitive function.[28] Considering that body-worn LC has been shown to induce postural instability,[9] adding cognitive tasks to quiet standing, commonly referred to as a dual task paradigm, may further reduce postural stability.[29] However, no studies to date have addressed the question of whether specific types of LEO body-worn LC are superior in terms of attenuating disturbance to postural stability during dual-task standing .

Law enforcement agencies vary in their LC requirements, with some mandating all equipment is worn on a belt and others allowing LEOs to load equipment onto a tactical vest. These decisions have not yet been supported by ergonomic evidence of maximized efficiency and minimized injury risk. Little is currently known about how the load distribution of duty belts and vests may affect muscular activity and postural stability while standing and performing cognitive assessments, all common LEO tasks.[24] Therefore the purpose of this study was to assess how different types of law enforcement LC systems affected the postural stability and muscular activity of participants while performing quiet standing and cognitive function tests. The hypotheses were: 1) either type of LC would decrease postural stability and increase muscular activity compared to no LC; 2) there would be no differences in postural stability or muscular activity between types of LC under both single and dual-task quiet standing; and 3) LC would impair cognitive function as compared to no LC.

2. Methods

2.1 Experimental Design and Participants

Participants visited the laboratory where data collection occurred during a single 120-minute session. During the single session, participants completed three conditions with a randomized cross-over design. Participants were asked to avoid strenuous exercise 12-hours before data collection. Upon arrival, participants gave an informed consent form approved by the

XXX University Institutional Review Board approved (IRB approval #: 1455213-1) informed consent and the Physical Activity Readiness Questionnaire (PAR-Q) to determine eligibility. A total of 29 healthy participants were recruited from the university population for this study, with five being removed due to equipment technical issues. Participants were included if they were between 18-45 years of age, had a body mass index below 30, and were recreationally active at least three days a week. Exclusion criteria were a previous history of lower back or other lower extremity injury within the past six months or the inability to deadlift a load equal to one's own body mass. A total of 24 participants completed data collection and were included in the analyses (13 male, Age: 24.50 yrs ± 6.00, Height: 169.30 cm ± 9.79, Mass: 73.0 kg ± 11.08, BMI: 25.40 kg/m^2 ± 2.42).

2.2 Belt Conditions and Randomization

The order in which participants wore the three load conditions was computer randomized prior to participant arrival. Condition 1 served as the control and the participant wore no load. Condition 2, participants wore a leather law enforcement utility belt loaded with pouches and a holster with a total mass of 7.2 kg. The holster was positioned on the participant's right side. Lastly, in condition 3, participants wore a 7.2 kg loaded vest to simulate a law enforcement duty vest. Prior to beginning data collection, participants' height was measured using a stadiometer (Detecto, Webb City, MO) and was recorded to the nearest 0.01 cm. Also, participants' mass was measured using a digital scale (Eat Smart, Salinas, CA, USA) and was recorded to the nearest 0.1 kg. Without wearing a load, participants performed a body weight warm-up of 10 bird-dogs, 5 inchworms, 12 body weight squats, and 12 body weight Romanian deadlifts (RDL) two times.

After warming up, participants completed all the single and dual-task standing tasks for all three load conditions.

2.3 Quiet Standing and Cognitive Function Assessments

The psychomotor vigilance task was used to assess participants' alertness and vigilance by evaluating reaction time.[30] Participants completed the psychomotor vigilance task while standing and using a trackpad on a laptop. Average reaction time over the two minute assessment was recorded. The Serial 7 test was used to assess how participants' muscle activity and center of pressure varied when wearing a load while information processing.[31,32] Prior to data collection, three numbers were randomly selected from between 100-106. Participants stood on two force plates, facing the researcher, and counted backwards by 7, out loud, from the number randomly chosen. For example: "106, 99, 92, 85...". For the dual communication task, participants were given a radio with an earpiece. While the participant stood on the force plates, researchers asked the participant two recall questions (i.e. What is your date of birth?) and two judgement questions (i.e. How would you rate the weather recently?) via radio. Participants answered via radio. Dual communicating has been used as a secondary task in dual task paradigm research.[33] Remaining on the force plates, participants crossed their arms across their chest and stood quietly. A 30 seconds period of data collection while quiet standing has been used in previous studies assessing the effect of load on center of pressure variables. The serial 7, dual communication, and quiet standing tasks were performed in the same order for each condition and both sEMG and center of pressure data were recorded for 30 seconds.

2.4 sEMG attachment

Prior to the warm-up, the surface electromyography (sEMG) electrodes were placed bilaterally along the multifidus, lower rectus abdominus, rectus femoris, and biceps femoris.-Skin site preparation and sEMG placement adhered to Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) guidelines.[34] All electrodes were placed parallel with the muscle belly and on common motor points following current best practices for sEMG placement.[34] Placement was guided by a reference chart, however, final placement was be determined through palpation of the participant by the researcher. Electrodes were attached with double-sided tape and further secured utilizing athletic training tape wrap around the participants limb and trunk to minimize shifting due to movement and sweat. To eliminate potential noise in the sEMG signals, all unnecessary electronics were removed from the testing area such as cell phones, electronics, and smart watches. The sEMG electrodes were worn throughout the entire duration of the testing procedure.

2.5 Data Collection and Processing

Delsys Trigno sEMG electrodes (Trigno, Delsys INC, MA, USA) were fully charged and paired with VICON Nexus before participant arrival. sEMG data were sampled at 2000 Hz and bandpass filtered (20 to 490 Hz) with a 4th order Butterworth filter. After rectification, the sEMG data were smoothed with a 5 Hz low pass filter. For each trial, the mean smoothed sEMG recording of each muscle was used in subsequent analyses. Data for individuals in which the sEMGs fell off during testing was removed. Each participant's control condition served as a reference point. Percent change from control to each load condition was calculated. This method of expressing load conditions relative to control has been used previously.[23] Force Plates (Bertec 4060-10, Bertec Corporation, Columbus, OH, USA) were warmed up at least 30-minutes prior to participant arrival and were zeroed prior to data collection. Center of pressure data were sampled at 2000 Hz then down sampled to 100 Hz. Force data was low-pass filtered with a 5Hz 4th order

Butterworth filter. Resultant, AP and ML center of pressure measures were computed to analyze both net and direction specific effects during the experimental conditions. Specifically, center of pressure anterior-posterior (AP) range, AP mean velocity, medial-lateral (ML) range, ML mean velocity, total mean velocity, and 95% ellipses area were computed. sEMG and force plate data was filtered and processed in MatLab (MatLab 2020a, MathWorks Inc., Natick, MA, USA), then exported to Microsoft Excel (Microsoft Excel, v16.59, Microsoft Corporation, Redmond, WA, USA) for further ~~cleaning~~ analysis.

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2.6 Statistical Analysis

Extreme values for muscle activity and center of pressure data were winsorized to three standard deviations at the 1st and 99th percentiles within Microsoft Excel. The winsorizing approach allowed all participants to remain in the data set that was used in the inferential statistical analysis. This is important given the relatively small sample and this minimizes the potential bias effects of extreme values on descriptive statistics. Winsorization has been used previously in research utilizing sEMG data.[35] Normality was assessed via the Shapiro-Wilk test. A majority of the data was not normally distributed. Thus, a non-parametric 3 x 3 factorial repeated measures analysis of variance (RM-ANOVA) was conducted on muscle activity (% change from control) and center of pressure measures using the Aligned Ranks Transformation (ARTool) function in R.[36] Where results were significant, pairwise comparisons with Bonferroni corrections were conducted.[37] Lastly, a RM-ANOVA was conducted to determine significant differences in psychomotor vigilance task scores between load conditions. All data analysis took place in the R environment using readr, dplyr, tidyr, and ARTool packages. Significance was set to $\alpha = 0.05$.

3. Results

3.1 Postural Stability

A significant task main effect was seen in all center of pressure variables (Table 1). Post hoc analysis revealed serial 7's resulted in greater AP range (t = 6.57, p < 0.001, d = 0.833), ML range (t = 5.12, p < 0.001, d = 0.511), mean velocity (t = 8.87, p < 0.001, d = 0.844), mean AP velocity (t = 8.81, p < 0.001, d = 0.832), mean ML velocity (t = 6.30, p < 0.001, d = 0.629), and 95% ellipse area (t = 5.49, p < 0.001, d = 0.631) compared to quiet standing. Additionally, dual communication resulted in a greater AP range (t = 5.41, p < 0.001, d = 0.622), ML range (t = 7.30, p < 0.001, d = 0.812), mean velocity (t = 7.92, p < 0.001, d = 0.766), mean AP velocity (t = 7.43, p < 0.001, d = 0.700), mean ML velocity (t = 9.12, p < 0.001, d = 0.984), and 95% ellipse area (t = 4.66, p < 0.001, d = 0.433) compared to quiet standing. There was significantly greater mean ML velocity (t = 2.83, p < 0.001, d = 0.355) during dual communication compared to serial 7's.

-------Table 1 Here-----------

3.2 Muscle Activity

There was a significant load condition main effect on the right rectus abdominus, left and right multifidus, right rectus femoris, and right biceps femoris (Table 2). Post hoc analyses found the belt had significantly more muscle activity than the control condition in the left multifidus (t = 3.31, p = 0.003, d = 0.524), right multifidus (t = 2.712, p = 0.022, d = 0.353), right rectus femoris (t = 2.476, p = 0.043, d = 0.233), and right biceps femoris (t = 2.528, p = 0.037, d = 0.225). In contrast, the belt resulted in significantly less muscle activity than the control in the right rectus abdominus ($t = 2.697$, $p = 0.023$, $d = 0.005$). Additionally, the vest had significantly more muscle activity than the control condition in the right multifidus ($t = 3.258$, $p = 0.004$, $d = 0.120$), right rectus femoris ($t = 3.989$, $p < 0.001$, $d = 0.482$), and right biceps ($t = 4.094$, $p < 0.001$, $d = 0.533$). The belt resulted in less muscle activity in the right abdominus ($t = 2.679$, $p = 0.024$, $d = 0.346$) but more muscle activity in the left multifidus ($t = 3.176$, $p = 0.005$, $d = 0.333$) compared to the vest condition.

There was a significant task main effect for muscle activity in all muscles except the right biceps femoris (Table 2). Post hoc analyses revealed that the serial 7's task resulted in significantly greater muscle activity in the left rectus abdominus ($t = 5.825$, $p < 0.001$, $d = 0.751$), right rectus abdominus ($t = 4.357$, $p < 0.001$, $d = 0.410$), left multifidus ($t = 3.030$, $p = 0.008$, $d = 0.228$), right multifidus ($t = 2.610$, $p = 0.029$, $d = 0.064$), and left rectus femoris ($t = 5.18$, $p < 0.001$, $d = 0.610$) compared to quiet standing. Similarly, the dual communications task resulted in significantly greater muscle activity in the left rectus abdominus ($t = 6.841$, $p < 0.001$, $d = 0.840$), right rectus abdominus ($t = 5.267$, $p < 0.001$, $d = 0.489$), right multifidus ($t = 4.526$, $p < 0.001$, $d = 0.288$), and left rectus femoris ($t = 4.287$, $p < 0.001$, $d = 0.454$) compared to quiet standing. Serial 7's resulted in significantly more muscle activity in the right rectus femoris ($t = 3.13$, $p = 0.006$, $d = 0.262$) but less in the left biceps femoris ($t = 2.605$, $p = 0.030$, $d = 0.182$) compared to dual communication.

There were significant interaction effects for all muscles except left biceps femoris (Table 2). Post hoc analyses for core muscles (rectus abdominus and multifidus) and lower extremity muscles (rectus femoris and biceps femoris) are displayed in table 3 and 4, respectively. Post hoc analyses for right rectus femoris and right biceps femoris revealed no further significant interaction ("none"). Interactions effects are visualized in Figures 1 and 2. Overall, the dual task paradigms (serial 7's and dual communication) increased muscle activity compared to quiet standing, with load (belt and vest) further increasing muscle activity compared to no load. However, quiet standing while wearing the belt resulted in less muscle activity within the left and right rectus abdominus compared to all three tasks in the control load condition.

-------Table 2 Here-----------

-------Table 3 Here-----------

-------Table 4 Here-----------

-------Figure 1 Here-----------

-------Figure 2 Here-----------

3.3 Cognitive Function

There was no significant difference in psychomotor vigilance task scores between conditions ($F_{(2, 23)} = 0.044$, $p = 0.923$).

4. Discussion

The purpose of this study was to compare how different types of law enforcement LC systems affected the postural stability and muscle activity of participants while performing single and dual-task quiet standing. The first hypothesis, that LC would decrease postural stability as compared to no load, is not supported by the results as there was no load condition main effect on center of pressure. However, a task main effect on center of pressure was observed, with dual-task quiet standing significantly increasing center of pressure variables. The second hypothesis, that there would be no differences in postural stability or muscle activity, between types of LC under both single and dual-task quiet standing is not supported by the results. When comparing

LC conditions, the belt resulted in less muscle activity in the right rectus abdominus but more muscle activity in the left multifidus compared to the vest condition. Additionally, the belt resulted in significantly more muscle activity in the low back and right thigh but less in the abdominals compared to the control condition. Also, the vest resulted in significantly more muscle activity than the control condition in the right multifidus and right thigh. A significant task main effect on muscle was observed with most muscles increasing muscle activity during cognitive function tasks compared to the single-task quiet standing. The third hypothesis, that LC would decrease cognitive function compared to no load, was not supported by the results. Psychomotor vigilance task reaction time scores were not significantly different between load conditions. There were no significant interactions between load conditions and the two cognitive tasks (i.e. no significant differences between cognitive function tasks).

The addition of a 7.2 kg load via belt or vest did not result in any change in postural stability compared to the control. A recent systematic review and meta-analysis found that generally load increases center of pressure measures, thus decreasing postural stability.[9] However, a majority of the studies included in the review incorporated heavier loads than the present study. For example, Heller et al.[38] used 18.1 kg military backpack loads and Punakallio et al.[17] used 25.9 kg firefighter protective equipment loads, with both studies observing decrements in postural stability. Kasovic et al[19] used 5 kg, 25 kg, and 40 kg loads and found that all significantly decreased postural stability. However, Park et al., found that a 9 kg loaded vest did not decrease postural stability.[11] This is similar to the current study where a 7.2 kg load, regardless of load condition, did not affect postural stability. In addition to being a lower absolute load, the belts and vests in this current study were loaded symmetrically such that the belt did not weight more heavily on one side than the other and the vest was equally loaded anterior-posteriorly. Thus, it is possible that 7.2 kg load used in the present study was below the threshold to induce changes in linear center of pressure measures.[39] However, based on the results of other studies, these results were unexpected.

Few studies have reported on the effects of body-worn LC on muscle activity measured via sEMG. The current study is congruent with previous literature in that load had a significant main effect on muscle activity.[10,11] Park et al. noted a significant increase in muscle activity in the rectus femoris while standing under a 9 kg load.[11] Likewise, Rice et al. noted increased vastus lateralis activity when wearing a 35.5 kg load.[10] Similarly, the current study found increased muscle activity in the rectus femoris and biceps femoris while loaded but only in the right leg. Also, increased muscle activity in only the right low back was observed. In comparing LC methods, the belt resulted in significantly less muscle in the right rectus abdominus and more in the left multifidus compared to the vest condition, the only difference between load conditions. It is plausible the right thigh and low back were preferentially affected due to a majority of individuals being right side dominant and therefore, compensating for load with their preferred side. However, the literature presents contrasting results on preferred footedness and asymmetrical responses to quiet standing.[40] Unfortunately, dominance was not recorded in the present study, but it could be speculated that a majority would be right-foot dominant.[41]

Additionally, the belt resulted in less muscle activity in the right rectus abdominus but more activity in the multifidus compared to the control condition. Thus, the belt condition may preferentially deactivate abdominals and increase activation in the multifidus. Asymmetrical muscular activation between left/right and anterior/posterior could be a risk factor for low back pain with the belt condition exacerbating this phenomenon.[42,43] Individuals exhibiting low back pain displayed increased low back muscle activity while holding a 12 kg load, similar to unaffected controls.[44] However, unlike controls, individuals with low back pain showed higher activation in global muscles (rectus abdominal and external oblique) but decreased muscle activity in local abdominal muscles (internal oblique).[44] In contrast, another study has shown increased muscle activity in both abdominal and low back muscles in low back pain patients while lifting load.[45] Nevertheless, altered muscle activity has been reported to occur in individuals with low back pain. It has been concluded that trunk muscle activity is highly variable in low back pain patients and a clear pattern may not be identifiable.[46] While none of the participants in the current study reported low back pain, due to inclusion criteria, it is plausible that long term body-worn LC and the resulting increased muscle activity asymmetry could contribute to the onset and persistence of low back pain.

Consistent with previous literature, a significant decrease in postural stability (i.e. increased center of pressure measures) while performing cognitive tasks (i.e. dual task quiet standing) was noted with no difference between the serial 7's and dual communication tasks.[27–29,47] Therefore, addition of a cognitive task, regardless of load, negatively affected postural stability with a moderate to large effect size. Likewise, addition of the cognitive tasks increased muscle activity in the trunk and left rectus femoris. It could be plausible that trunk and left rectus femoris muscle activity increased to attempt to counteract decrements in postural stability induced by conducting a cognitive task.[48] This is in contrast to previous literature that showed increased postural stability and increased muscle activity in the lower limbs while balancing and undergoing psychological pressure[49] and decreased postural stability and decreased muscle activity in the lower limbs during stationary standing work.[50] However, literature has shown increases in erector spinae activity while standing and counting backwards out loud [51]and increases in quadriceps activity while standing, performing mathematics problems and the

Stroop's Color and Word Task.[52] Thus, while the relationship between muscle activity and center of pressure is unclear, there is evidence that cognitive dual tasks increase muscle activity. Overall, the culminating effects of decreased postural stability and increased muscle activity may present a mechanism for injury while standing and performing cognitive tasks, regardless of presence or absence of load.[15,53] The present findings are particularly noteworthy when considering a leading cause of injury in first responder populations is slips, trips, and falls[4] which is inherently characterized by decreased postural stability.

When analyzing interaction effects and comparing conditions within a task, none were significantly different except the control resulting in more muscle activity in the left and right rectus abdominus during quiet standing compared to the belt. This further supports the conclusion that the belt condition may result in lower abdominal muscle activity, a risk factor for low back pain.[42] All significant interactions paired the control and/or quiet standing and one of the cognitive function tasks together. Thus, type of cognitive task may not have as much of an effect as simply the presence of a cognitive task. It is plausible that the Serial 7's and Dual Communication tasks were too similar in nature to elicit different muscle activity and center of pressure responses from one another.[54] The Dual Communication task involved recall questions that could fall under the component of memory skills in executive functioning.[54] Likewise, a mental arithmetic task, such as counting backwards in the Serial 7's, is used to assess attention, concentration, and working memory, also components of executive function.[32] Thus, both cognitive function tasks included in this study may be assessing a similar domain of cognitive function and would not be expected to result in different outcomes on muscle activity and center of pressure.[55] Memory, attention, and concentration are integral components of LEO duties such as communicating clearly with dispatch, writing reports, and focusing on a primary target or task when multiple stimuli are presented.[25] Future studies should assess how dual task paradigms, that incorporate a different domain of cognitive function, affect muscle activity and center of pressure.

4.1 Limitations

There are several methodological limitations to the present study. First, the participants were young, healthy college students whereas the target population for our findings is LEOs. College students are subjected to some body-worn LC in the form of backpacks that can weigh over 5 kg.[56] However, backpacks are posterior only whereas vests and belts spread the load evenly. The findings of this study could be generalized to recruits first entering the police force who have no prior, or limited, LC experience. It has been documented that LEO recruits exhibit high injury rates.[57,58] Second, participants only wore the belt and vest for approximately 15-20 minutes each. Individuals tasked with carrying load, such as LEOs, often have prolonged exposure which may affect their responses to load differently. In the current study, the short duration LC may not have been long enough to observe transient negative effects, due to fatigue of LC, that have been realized in long duration LC studies.[10,16] Future studies should analyze how longer durations of belt and vest wear, such as 8-12 hours, effect muscle activity and center of pressure over the duration of a typical shift. Lastly, the 7.2 kg load was absolute but represented a different relative load per participant (body mass range: 52.0-92.2 kg, relative load range: 7.8%-13.8%). Loads that represent a greater relative mass may induce different effects as it could increase the metabolic demand in one participant versus another.[59,60] The loads the LEOs carry are absolute in nature and cannot often be scaled to their own body mass. Thus, the effects of loads on LEOs may be individualized and those who are smaller or weaker could be more affected by LEO LC. We would suggest that, in addition to measuring height and mass of participants, body composition (fat free mass and fat mass) and measures of strength should be incorporated into future studies to control for these confounding factors.

5. Conclusion

The addition of a load via a law enforcement duty belt or vest had no effect on postural stability but did result in increased muscle activity. LEO duty belts may preferentially deactivate the abdominal muscles, especially during quiet standing, thus increasing the risk for low back pain. [42,43] Since LEOs are continuously preforming cognitive tasks, subsequent decrease in postural stability and increase in muscle activity, due to dual task paradigms, may be of concern when ascertaining low back pain risk or injury due to falling in this population. While few differences were found between belt and vest conditions, the results of this study do not overwhelmingly support one method of LC over the other based on the acute effects of these forms of load carriage. Regardless, this is the first study to compare biomechanical outcomes between the two common types of law enforcement load carriage and can assist to guide researchers in the future.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability Statement

The data and code that support the findings of this study are available from the corresponding author, XX, upon reasonable request.

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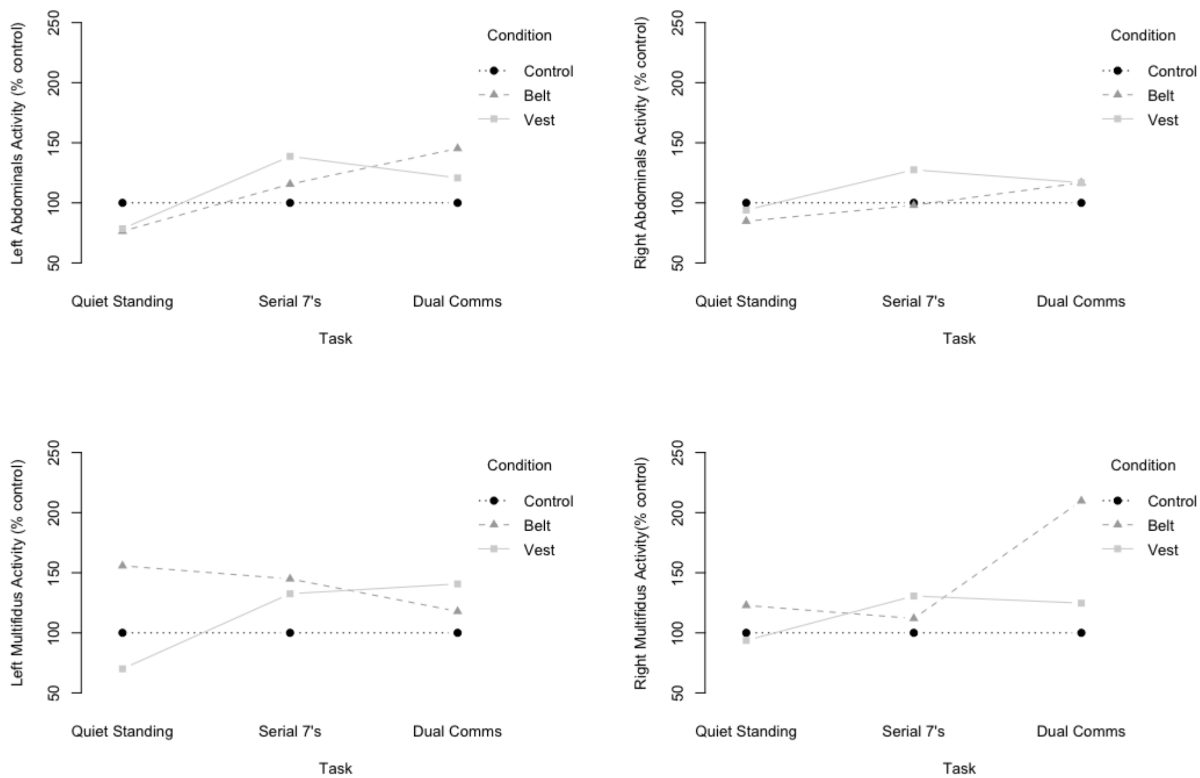
Figure 1. Overview of Experimental Procedures

1	Informed Consent & Screening
2	Demographics, Anthropometrics, and Questionnaires
3	Surface electromyography electrode placement
4	General Warm-up
5	Randomized Condition Assignment
6	Psychomotor Vigilance Task
7	Serial 7's
8	Dual Communication
9	Quiet Standing
10	Repeat steps 6 to 9 for other 2 conditions

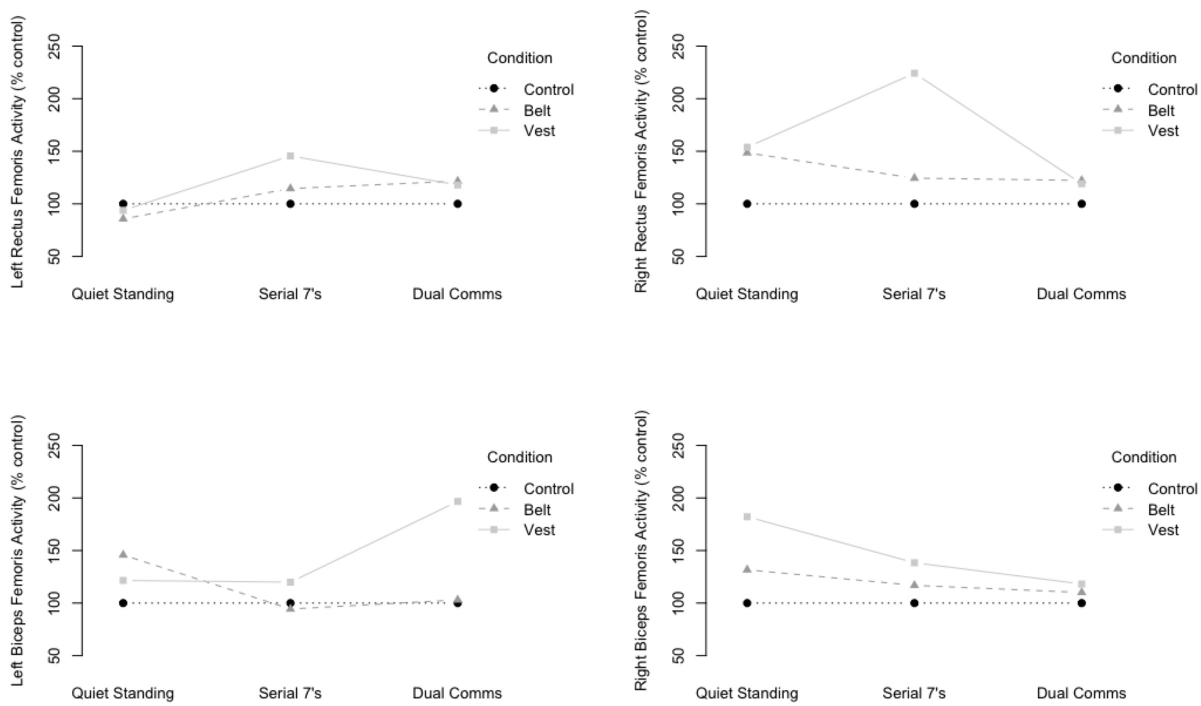
Note: Conditions were a control (no load), leather law enforcement style utility belt and tactical vest. The belt and vest both had a mass of 7.2 kg.

Figure 2. Interaction Plots for Muscular Activity in Trunk Muscles



Note: Interaction plots for the 3x3 factorial ~~RM-ANOVA~~ repeated measure analysis of variance on ~~MA~~ muscle activity in trunk musculature. Significant interaction annotation is included in Table 3.

Figure 3. Significant Interaction Plots for Muscular Activity in Lower Extremity Muscles



Note: Interaction plots for the 3x3 factorial ~~RM-ANOVA~~ repeated measure analysis of variance on ~~MA~~ muscle activity in lower limb musculature. Significant interaction annotation is included in Table 4. Interaction for Left Biceps Femoris is non-significant.

Table 1. Results of Factorial RM-ANOVA on Center of Pressure Variables

Center of Pressure	*F*-Statistic	*p*-value	η_p^2	Post-hoc Results
Condition - Main Effect (df = 2, 46)				
Range AP	0.177	0.838	0.002	
Range ML	2.189	0.115	0.023	
Mean Velocity	0.041	0.960	<0.001	
Mean Velocity AP	0.084	0.919	<0.001	
Mean Velocity ML	1.142	0.321	0.012	
95% Ellipse Area	1.373	0.256	0.015	
Task - Main Effect (df = 2, 46)				
Range AP	24.598	<0.001*	0.211	S7 > QS; DC > QS
Range ML	28.1185	<0.001*	0.234	S7 > QS; DC > QS
Mean Velocity	47.471	<0.001*	0.340	S7 > QS; DC > QS
Mean Velocity AP	44.904	<0.001*	0.328	S7 > QS; DC > QS
Mean Velocity ML	43.643	<0.001*	0.323	S7 > QS; DC > QS
95% Ellipse Area	17.495	<0.001*	0.160	S7 > QS; DC > QS
Interaction - Main Effect (df = 4, 92)				
Range AP	0.375	0.826	0.008	
Range ML	1.882	0.115	0.039	
Mean Velocity	0.520	0.721	0.011	
Mean Velocity AP	0.630	0.642	0.014	
Mean Velocity ML	0.730	0.573	0.016	
95 % Ellipse Area	0.847	0.497	0.018	

Key: AP - anterior-posterior, ML - medial-lateral, QS - quiet standing, S7 - Serial 7's, DC - dual communications. Partial Eta^2 interpretation: 0.01 - 0.06 = small, 0.06 - 0.14 = medium, > 0.14 = large. A significant main effect of task was found for all center of pressure variables. Post-hoc results reveal that both serial 7's and dual communications dual tasks increase center of pressure variables compared to quiet standing.

Table 2. Results of Factorial RM-ANOVA on Muscular Activity

Muscle	*F*-Statistic	*p*-value	η_p^2	Post-hoc Results
Condition - Main Effect (df = 2, 46)				
LAB	0.277	0.758	0.003	
RAB	4.816	0.009*	0.050	belt<control; belt<vest
LMF	7.075	0.001*	0.071	belt>control; belt>vest
RMF	6.090	0.003*	0.062	belt>control; vest>control
LRF	2.160	0.118	0.023	
RRF	8.109	<0.001*	0.081	vest>control
LBF	1.165	0.314	0.013	
RBF	8.533	<0.001*	0.085	belt>control; vest>control
Task - Main Effect (df = 2 , 46)				
LAB	27.255	<0.001*	0.229	S7 > QS; DC > QS
RAB	15.851	<0.001*	0.127	S7 > QS; DC > QS
LMF	4.777	0.009*	0.049	S7 > QS
RMF	10.324	<0.001*	0.101	S7 > QS; DC > QS
LRF	15.341	<0.001*	0.143	S7 > QS; DC > QS
RRF	4.925	0.008*	0.051	S7 > DC
LBF	3.477	0.033*	0.036	S7 < DC
RBF	2.562	0.080	0.027	
Interaction - Main Effect (df = 4, 92)				
LAB	6.690	<0.001*	0.127	See tables 3 & 4
RAB	4.335	0.002*	0.086	
LMF	9.841	<0.001*	0.176	
RMF	4.916	<0.001*	0.097	
LRF	6.833	<0.001*	0.129	
RRF	4.925	0.014*	0.065	
LBF	1.225	0.302	0.026	
RBF	2.969	0.021*	0.061	

Key: L - left, R - right, AB - abdominals, MF - multifidus, RF - rectus femoris, BF - biceps femoris, QS - quiet standing, S7 - serial 7's, DC - dual communications. Partial Eta^2 interpretation: 0.01 - 0.06 = small, 0.06 - 0.14 = medium, > 0.14 = large. A significant main effect of condition, task, and interaction effect was found for a majority of muscles.

Table 3. Results of Interaction Between Condition and Task for Trunk Muscular Activity

Right Abdominals				Left Abdominals			
Comparison	*t*-Stat (df=23)	*p*-value	*d*	Comparison	*t*-Stat (df=23)	*p*-value	*d*
C, QS - B, QS	3.394	0.030	0.410	C, QS - B, QS	3.458	0.024	0.536
C, S7 - B, QS	3.394	0.030	0.410	C, S7 - B, QS	3.458	0.024	0.536
C, DC - B, QS	3.394	0.030	0.410	C, DC - B, QS	3.458	0.024	0.536
B, QS - B, DC	-3.272	0.046	-0.858	B, QS - B, DC	-5.440	<0.001	-1.562
B, QS - V, S7	-4.186	0.002	-1.148	B, QS - V, S7	-6.351	<0.001	-1.414
B, QS - V, DC	-4.192	<0.001	-0.859	B, QS - V, DC	-6.208	<0.001	-1.006
V, QS - V, DC	-3.949	0.004	-0.610	V, QS - V, DC	-5.781	<0.001	-0.958
				B, S7 - V, QS	4.332	<0.001	0.840
				B, DC - V, QS	5.014	<0.001	1.514
				V, QS - V, S7	-5.925	<0.001	-1.365
				B, QS - B, S7	-4.758	<0.001	-0.889
Right Multifidus				**Left Multifidus**			
V, QS - V, DC	-4.020	0.003	-0.227	V, QS - V, DC	-5.401	<0.001	-0.937
				B, S7 - V, QS	5.373	<0.001	0.993
				B, DC - V, QS	3.824	0.006	0.634
				V, QS - V, S7	-4.290	0.001	-0.829

Key: C- Control, B - Leather Belt, V - Vest, QS - Quiet Standing, S7 - Serial 7’s, DC - Dual Communication. Cohen’s D Interpretation: small - 0.2, medium - 0.5, large - 0.8. Gray shading indicates significant interactions observed on the left and right side muscles.

Table 4. Results of Interaction Between Condition and Task for Lower Limb Muscular Activity

Left Rectus Femoris			
Comparison	*t*-Stat (df=23)	*p*-value	*d*
B, QS - B, DC	-4.020	0.003	-0.815
B, QS - V, S7	-4.194	0.002	-1.036
B, QS - V, DC	-3.540	0.018	-0.732
B, DC - V, QS	3.306	0.041	0.632
V, QS - V, S7	-3.481	0.022	-1.176

Key: C - Control, B - Leather Belt, V - Vest, QS - Quiet Standing, S7- Serial 7's, DC - Dual Communication. Cohen's D Interpretation: small - 0.2, medium - 0.5, large - 0.8.
Note: Although a main interaction effect was statistically significant, post-hoc pairwise comparisons revealed no further significant interactions for the right RF and the right BF.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: