International Journal of EXERCISE SCIENCE

Original Research

Forces at the Feet, Gait Timing, and Trunk Flexion/Extension Excursion While Walking with a Gear Belt or Gear Vest Load

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ABSTRACT

International Journal of Exercise Science 15(1): 36-44, 2022. Law enforcement personnel often carry gear loads, which have a history of causing low back pain. The aim of this study was to evaluate the differences in gait and trunk posture for gear load carried on a gear belt and a gear vest. Twenty-nine participants performed load carriage in three conditions: a no load control trial (C), a symmetrically loaded gear belt (GB), and an anterior-loaded gear vest (ALV). Gear conditions had 9.07 kg of additional mass. Motion capture and insole force sensors were used to collect data while participants walked on a treadmill for three minutes per condition. Mean insole reaction force was significantly greater in both GB and ALV conditions as compared to C ($p < 0.001$). Mean gait cadence in the GB or ALV condition were not significantly different from the C condition. However, double support time in the ALV condition was significantly longer compared to C condition ($p = 0.023$). Stance duration on the left foot was significantly longer with the GB ($p = 0.001$) and ALV ($p = 0.028$) when compared to C. Results showed trunk flexion/extension excursion was significantly less in the GB condition when compared to the C condition ($p = 0.002$). These findings demonstrate that law enforcement and other personnel who walk while carrying gear loads may experience altered biomechanics compared to unloaded walking. Altered biomechanics and increased forces on the feet could potentially increase risk of musculoskeletal injury while carrying gear loads.

KEY WORDS: Load carriage, force sensor, law enforcement, motion analysis, police

INTRODUCTION

Law enforcement agents often carry gear or equipment loads, which have a history of causing low back pain (5, 6, 24). Low back injuries were reported as 19.6 % of law enforcement injuries in 2020 (13). Load distribution can affect trunk posture, gait timing and force distribution at the foot (25), and the distribution of load may contribute to back pain (6, 7). Traditionally, law enforcement equipment is carried on a belt (6). Other forms of load carriage can include over the shoulders with a backpack or a gear vest (4, 16, 25).

Gear can be carried by law enforcement in a symmetric (17) or asymmetric manner (18, 19, 21, 29). Few studies have examined gait mechanics in law enforcement personnel, whose gear is often between 8 and 12 kg (18, 19). But comparisons can be made to other personnel, such as military or first responder, who also carry gear loads. Load carriage in military personnel carrying weights over 15 kg has been studied extensively demonstrating increases in measures such as energy expenditure and ground reaction forces with load carriage (3, 11, 12, 22, 26). Symmetrical load carriage has demonstrated decreased oxygen consumption compared to asymmetrical loading (16, 31). With an anterior-posterior symmetric vest load, trunk posture changed within several gait cycles (16). However, law enforcement, military, and first responders often carry asymmetric loads. Trunk angle has been used to characterize differences in walking trials with asymmetric backpack load (27). In contrast to military and first responders who carry heavy gear posteriorly in backpacks (10, 27), law enforcement often carries gear less than 12 kg on a vest with the gear positioned anteriorly for easy accessibility. Past studies have evaluated performance measures during law enforcement load carriage (18, 19). This study aims to add to knowledge of gear loads commonly carried in law enforcement by comparing the effects of a symmetrically loaded gear belt and an anterior-loaded gear vest on walking gait.

Law enforcement personnel often work 10 to 12 hour shifts while carrying gear (30). Investigating how gear load can affect trunk posture, gait timing and forces at the feet could possibly provide insight to injury prevention. The purpose of this study is to evaluate gait differences and trunk posture during load carriage with a gear belt and a gear vest while walking. We hypothesized that there would be a difference in forces on the feet, gait timing and trunk flexion/extension angle while distributing equipment weight on a gear belt and a gear vest as compared to a no-load condition.

METHODS

Participants

Twenty-nine (15 females, 14 males) healthy participants provided informed written consent to forms and protocols approved by the California State University San Marcos Internal Review Board (IRB #130844-1). This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (20). Statistical software G*POWER (Universitat Keil, Germany) was used to determine that 25 participants were needed to power the study with a medium effect size for an $\alpha = 0.05$. Participants were recruited as a convenience sample from a university setting. Participant characteristics are given in Table 1. Volunteers were screened and excluded for history of heart disease, neurological disorders, or brain, back, or neck injury that could interfere with walking while carrying load. Participants were instructed to wear athletic clothing and running footwear. Foot length was measured to determine size for an insole sensor.

Table 1. Characteristics of participants given as mean ± standard deviation

	Age (years)	Height (cm)	Mass (kg)	Shoe Size (US)
Female (n = 15)	26.5 ± 4.8	165.4 ± 7.5	73.1 ± 11.4	8.0 ± 0.9
Male (n = 14)	25.2 ± 4.0	177.5 ± 5.7	81.2 ± 12.0	10.5 ± 0.7

Protocol
Load carriage was performed in three conditions: a control trial with no gear weight (C), a nylon tactical gear belt (GB, Yaemart Corporation, Azusa, CA), and an anterior-loaded gear vest (ALV, TacTec Vest, 5.11 Tactical, Irvine, CA). The equipment and amount of load was chosen after consultation with a local police department (Oceanside, CA) on standard gear. The GB and ALV were chosen to replicate a vest and belt used by law enforcement. Gear conditions had 9.07 kg of load. Order of conditions was randomized. Standard law enforcement equipment holders distributed symmetrically around the 5.1 cm wide GB held small weights to total 9.07 kg. For ALV condition, 75% of the weight was in the anterior compartment of the vest with plates (Rogue Fitness, Columbus, OH), with the remaining weight in the posterior compartment. The vest was loaded with most of the weight placed anteriorly as law enforcement officers often carry most of their gear on the front of the vest to allow for accessibility. The GB and ALV were properly fit to each participant using adjustable straps. Trials consisted of treadmill walking at a pace of 1.12 m/s for 3 minutes.

Moticon Force Sensor Insoles (Munich, Germany) of the correct size were placed in the participant's shoes to measure the forces and gait timing. Before trials were collected, each insole force sensor was calibrated. Calibration was achieved by participants standing on one foot so that the foot off the ground was calibrated to zero force. Sampling rate for the insole force sensors was 50 Hz. Three-dimensional forces and gait timing were measured for several complete gait cycles.

An 8-camera motion capture system (Qualisys AB, Goteborg, Sweden) was used to acquire the positions of 9-mm reflective markers at a 120 Hz sampling rate to compute trunk angle while participants walked on a treadmill. Reflective markers were placed on the following 12 locations: left and right acromial processes, cervical spine (C7), sternum, left and right anterior superior iliac spines, left and right posterior superior iliac spines, and left and right greater trochanters. Participant stood for 5 seconds in the anatomical position before each load condition to verify marker placement. Markers were not removed between conditions. Visual 3D software (C-Motion, Germantown, MD) was used to create a thorax model to compute trunk flexion/extension angle from the recorded marker positions relative to a vertical axis in the laboratory (9, 23). Anterior trunk flexion was denoted as a positive angle.

Statistical Analysis
Trunk flexion/extension, along with gait timing and ground reaction forces were compared among gear conditions. Measurements of the left and right foot were also compared for force magnitude and gait timing measures recorded with the insole sensors. The middle minute of each three-minute walking trial was analyzed. Mean and standard error (SE) were computed for force magnitude and gait timing measures. Gait timing measurements included mean gait cycle time, mean cadence, double support time, and stance duration. Trunk flexion/extension excursion was calculated by finding the difference between the minimum and maximum trunk angle in the sagittal plane during the middle minute of the walking trial. Mean and standard error were computed for each trunk posture measure. SPSS (IBM, Inc., Armonk, NY) was used for statistical analysis. Repeated measures analysis of variance (RMANOVA) was used with

Bonferroni's post-hoc test to compare trunk flexion/extension excursion among conditions. Measurements taken with the insole sensors were statistically compared using two-way RMANOVA with gear condition and foot (right and left) as the factors. Partial eta squared was used for effect size. Statistical significance was set at $p < 0.05$.

RESULTS

For three participants, the insole sensor data were not complete on both left and right feet, so data for twenty-six participants were used in the force and gait timing comparisons. There was main effect for gear condition on insole sensor forces ($n = 26$, $F = 27.286$, $p < 0.001$, effect size = 0.522). Mean insole force for both weighted gear conditions was significantly greater than the control condition ($p < 0.001$, Figure 1). There was no significant difference between mean insole forces of the left foot and right foot in any of the three load conditions. There was no significant interaction of gear condition and foot on insole forces. The percent change in forces at the foot from the control was 9.7% for the left foot and 8.8% for the right foot in the GB condition, and 8.3% for the left foot and 9.2% for the right foot in the ALV condition.

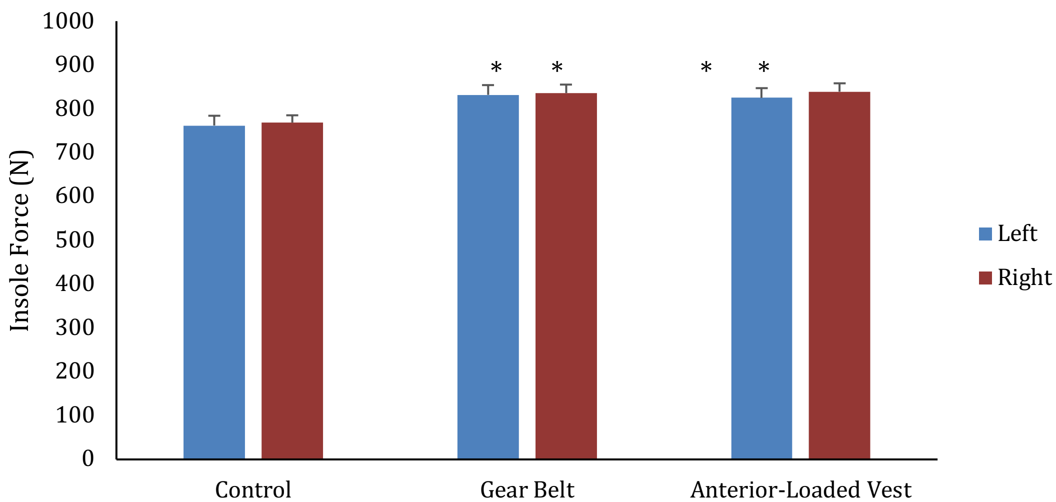

Figure 1. Mean insole force measured while walking ($n = 26$). Error bars represent standard error. Both gear belt and anterior-loaded vest gear conditions demonstrated significantly greater force on left and right feet when compared to the control condition. *denotes significantly different from no load control condition ($p < 0.001$).

No differences were measured in mean gait cycle time when comparing the C condition to the GB carrying condition ($p = 0.886$) or the ALV condition ($p = 0.332$). Mean ± SE gait cycle time was 1.13 ± 0.01 s for the ALV condition, 1.14 ± 0.01 s for the TB condition, and 1.14 ± 0.01 s for the C condition. Neither the GB or ALV condition were significantly different for cadence then the C condition ($p = 0.097$ and $p = 0.053$, respectively). Mean gait cadence was greatest in the ALV condition, with a mean of 53.9 ± 0.7 strides/min. The GB condition had a mean gait cadence of 53.2 ± 0.5 strides/min and the C condition had a mean gait cadence of 53.0 ± 0.5 strides/min.

Mean double support time in the ALV condition was significantly greater than in the C condition ($F = 4.158$, $p = 0.023$, Figure 2). Effect size for double support time was 0.143. Double support time in the ALV condition averaged 0.35 ± 0.02 s. Mean double support time for the GB condition was 0.34 ± 0.01 s and for the C condition was 0.32 ± 0.01 s. There was no difference when comparing double support time in the GB condition to either the C or the ALV condition (p = 0.367 and p = 0.628, respectively).

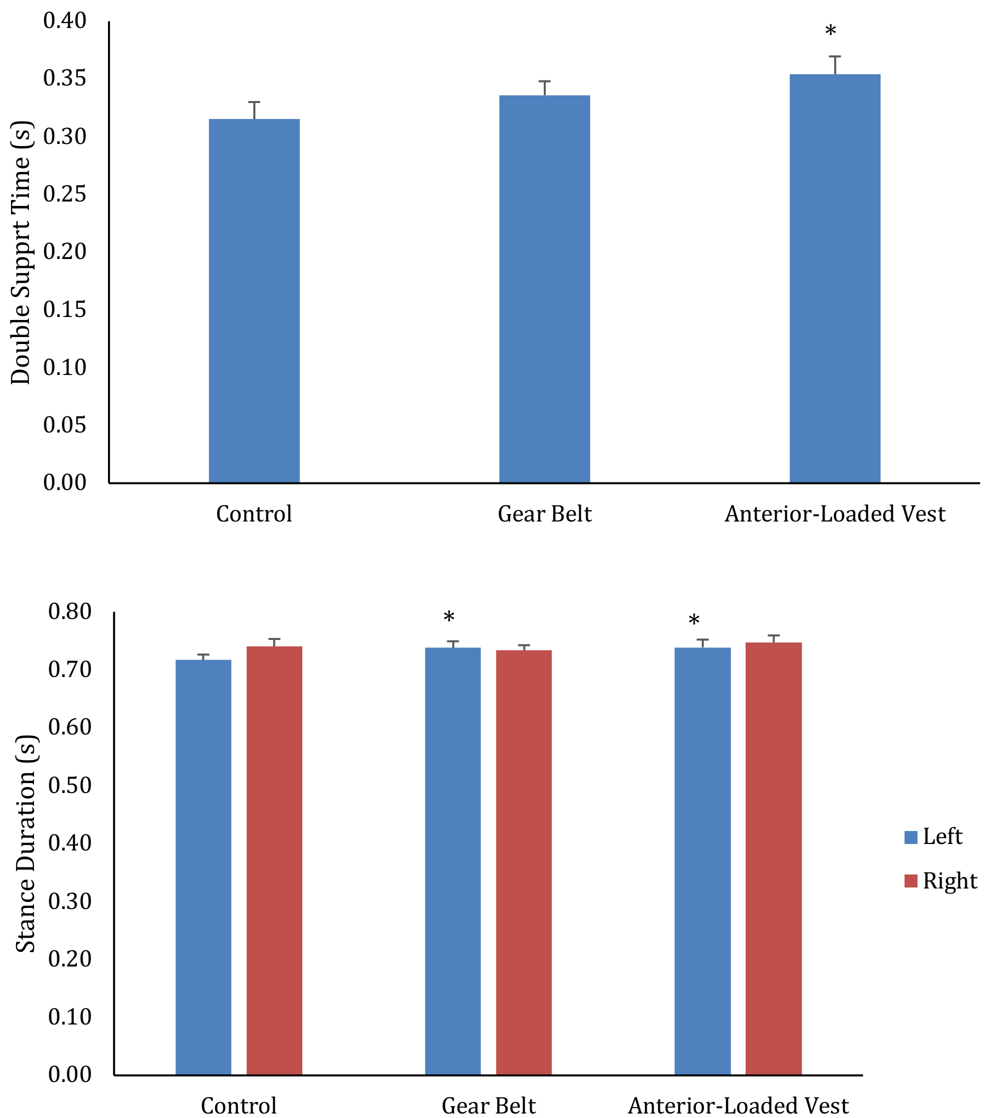

Figure 2. Gait timing comparison for participants (n = 26) while walking in each load condition. Mean double support time (top) for the anterior-loaded gear vest condition demonstrated significantly longer double support time compared to the control condition. Left foot (blue bar) and right foot (red bar) measures are reported for stance duration (bottom). *denotes significantly different from the control (p < 0.05).

There was a main effect of gear load on stance duration (F = 4.943, p = 0.011, effect size = 0.167). Specifically, in the GB condition, stance duration averaged 0.74 ± 0.01 s for the left foot and 0.73 ± 0.01 s for the right foot (Figure 2), and the left foot stance duration was significantly greater than in the C condition (p = 0.001). The ALV condition mean stance duration was also significantly greater for the left foot when compared to C condition (p = 0.028). When comparing stance duration between the GB gear condition and the ALV gear condition there was no significant difference on the left or right foot ($p \geq 0.417$).

For mean trunk flexion/extension excursion, there was a main effect of gear load condition (n = 29, F = 3.394, p = 0.041, effect size = 0.108). Mean trunk flexion excursion in the sagittal plane while walking was greatest for the C condition, with an average of 7.94 ± 0.32° of anterior flexion excursion (Figure 3). The GB condition had a mean trunk flexion/extension excursion that was significantly lower trunk excursion as compared to the C condition (p = 0.034). Mean trunk flexion excursion for ALV was not significantly different than the C or GB condition. The mean trunk flexion angle while walking was greatest for the C condition, with a mean of 0.99 ± 0.57° of anterior trunk flexion. Trunk angle for the GB and the ALV conditions were -0.37 ± 0.55° of trunk extension and 0.55 ± 0.66° of trunk flexion, respectively. The GB condition was significantly different from the C condition for trunk flexion (p = 0.002), but the ALV condition was not different from the C condition (p = 0.507). There was no difference in mean trunk flexion angle between GB and ALV gear conditions (p = 0.324).

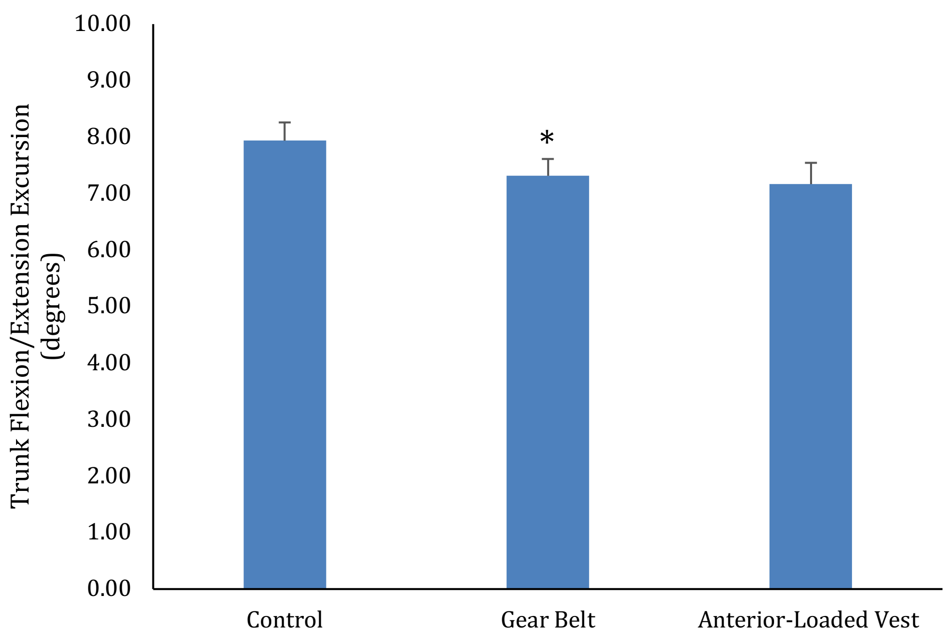

Figure 3. Mean trunk flexion/extension excursion in the sagittal plane for each load condition while walking (n = 29). Error bars represent standard error. *denotes significantly different from the control condition ($p < 0.05$).

DISCUSSION

The purpose of this study was to evaluate the effect of a gear belt and a gear vest load on trunk posture and gait parameters during walking. Our hypothesis that there would be a difference measured in gait timing, forces on the feet, and trunk flexion with gear load was supported by the findings in this study. Specifically, double support time increased when participants carried gear load as compared to the no-load control condition. Gait timing results were consistent with previous research demonstrating increased double support time during walking with other types of load carriage (1, 21). The results show that participants increased the time spent in the double support phase of walking when carrying an anterior-loaded gear vest without changing the overall gait cycle time or cadence. Our hypothesis was also supported by changes in insole forces measured when adding a gear load. Additionally, carrying a loaded gear belt also had effects on trunk posture while walking. This finding is similar to previous research that demonstrated trunk posture changed depending on whether a load was carried anteriorly in the hands or posteriorly in a backpack (1, 15). Although differences in gait timing and forces at the feet were demonstrated when carrying a gear load when compared to the no load control condition, there were no significant differences between the gear belt and gear vest load conditions.

This research had limitations including variation in athletic shoes worn by each participant. However, the insole force sensors fit into all shoes without causing discomfort and provided data for all participants. The insole force sensors used have been shown to have a 13-30% difference from a calibrated force platform (28). Previous research by Silder et al. (27) found that with a 10% increase in load, ground reaction force increased by 6%. The current findings for reaction forces measured are similar to past research as insole reaction forces increased by approximately 8-9% of the 88.98 N of gear load.

Gear loads of 12 kg or less have been shown in previous research to have significant impact on performance and physical ability. Previous research has examined gear load carriage during obstacle course agility tests (29), and sprinting (14). Additionally, past literature shows officers had longer completion times on physical ability tests while wearing 12 kg of gear (19) and reduced performance on strength and cardiorespiratory tests while wearing 8.3 kg of gear (18). The current findings suggest that gear loads less than 10 kg can also affect gait and posture during walking. It is important to understand the changes to biomechanics induced by gear load carriage during walking because law enforcement personnel may spend part of their shift walking (2, 8). Trunk flexion angle and excursion were affected by carrying a gear belt loaded symmetrically around the belt. Quantitative measures of trunk flexion changes with gear load provide information to aid investigation of back injury risk and prevention in law enforcement. The present study adds to the current knowledge of gear carriage by clearly comparing the same load amount carried on a gear belt and a gear vest while walking.

In conclusion, changes in the gait timing, forces at the feet, and trunk flexion/extension excursions were observed with the addition of a 9.07 kg gear load carried on either a tactical belt or an anterior-weighted vest while walking. Gear load contributed to small but consistent adaptations in gait parameters. Understanding the changes to biomechanics with gear load on a symmetrically-loaded belt and an anterior-loaded vest sets a framework to investigate the risk factors for injuries in law enforcement, military, and first responder personnel who carry gear loads in different configurations for long shifts or prolonged periods of time.

ACKNOWLEDGEMENTS
The authors thank Richard Armenta, Matthew Becker and Jaundis Roxas for their contributions. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. Declarations of interest: none.

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