# IMPACT OF CARRYING HEAVY LOADS ON POSTURAL SWAY AND RELATIVE GROUND REACTION FORCES DURING QUIET STANCE IN INTERVENTION POLICE OFFICERS

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**Abstract:**

Although carrying heavy loads impacts gait characteristics in military personnel, less studies have examined whether a gradually load increase affects foot parameters during quiet standing in the different population of intervention police officers. Therefore, the main purpose of the study was to examine differences in postural sway and ground reaction force characteristics during a quiet stance while carrying progressively heavier equipment. Ninety-six elite intervention male police officers were assessed under four conditions: (i) 'no load', (ii) 'a 5 kg load', (iii) 'a 25 kg load', and (iv) 'a 45 kg load'. Foot characteristics during standing were assessed with the Zebris pedobarographic pressure platform. Heavier loads increased 95% confidence ellipse area ($p=.012$, $\eta2=0.028$), the center of pressure path length ($p=.010$, $\eta2=0.029$) and average velocity ($p=.011$, $\eta2=0.029$), and length of the minor ($p<.001$, $\eta2=0.040$) and major axis ($p=.004$, $\eta2=0.035$). No significant changes in relative ground reaction forces beneath the forefoot and hindfoot regions of both feet were observed ($p>.05$). The findings suggest that spatial and temporal foot parameters may be more prone to change while carrying heavy loads, especially the center of pressure characteristics.

***Keywords:*** *special population, foot characteristics, center of pressure, statics, equipment, changes*

## Introduction

Carrying excessive load represents a major part of both training and operation protocols in special population of military and police personnel (Brushøj, et al., 2008; Knapik, Reynolds & Harman, 2004; Wills, Saxby, Lenton & Doyle, 2021). Although such load is important for combat missions and specific tasks, it has been shown that it impacts optimal locomotor functions, increases the risk of lower limb injury (Wills, et al., 2021), and hampers physical performance (Boffey, et al., 2019; Martin, Kearney, Nestrowitz, Burke & Sax van der Weyden, 2023). Unfortunately, a negative trend in load weight has been observed, surpassing the recommended level of 45% of body mass (Andersen, Grimshaw, Kelso & Bentley, 2016; Orr, Coyle, Johnston & Pope, 2015). From a relative perspective, evidence shows that the load necessary for meeting tactical requirements ranges between 46% and 70% of body weight (Department of the Army, 2017).

When carrying heavy loads, an individual often tends to compensate, causing changes in gait and posture characteristics (Fox, Judge, Dickin & Wang, 2020). From a biomechanical point of view, heavy equipment during walking may impact balance, movement and overall postural stability, leading to greater torques in hip and trunk areas, which can cause alterations in body control (Heller, Challis & Sharkey, 2009). However, little evidence has been provided regarding carrying heavy loads and foot stability during quiet stance (Kasović, Vespalec & Štefan,, 2022; Richmond, Fling, Lee & Peterson 2021; Schiffman, Bensel, Hasselquist, Gregorczyk & Piscitelle , 2006; Walsh & Low, 2021;). In the process of quantifying the effects of load carriage in a stance position, first changed activity of anti-gravity muscles of the trunk should be observed, then, the postural sway as well as spatial- and temporal-related foot parameters, which may lead to higher incidence of injuries (Kroemer & Grandjean, 1997). The importance of establishing changes in biomechanical foot parameters in police officers during stance comes from a high prevalence of standing and less moving activities due to sitting in a patrol car or doing administrative tasks for a long period of time, which may lead to sedentarism (Orr, Hinton, Wilson, Pope & Dawes, 2020). The ability of standing still and remaining postural control while carrying heavy loads is important for balance control of the body, where heavier loads tend to trigger appropriate motor responses to avoid its loss or injury/fall (Pollock, Durward, Rowe & Paul, 2000). Even though a standing position seems relatively safe, an external load placement and the magnitude of an increased postural sway and a decreased base of support (considering feet together) represents one of the main problems causing muscle strains and negative body adaptations (Zultowski & Aruin, 2008). Although external load is important for survival, it may increase the risk of injury due to requirements to repetitively generate muscular force, causing whole-body fatigue and increasing energy costs connected to prolonged load carriage (Fallowfield, Blacker, Willems, Davey & Layden, 2012; Tahmasebi, Karimi, Satvati, & Fatoye, 2015). Indeed, evidence suggests that deviations of the center of pressure can predict future risk of injury and postural instability through shorter intervals in mediolateral axis (Blacker, Fallowfield, Bilzon & Willems, 2010), causing ligamentous damage, especially in the lower extremities (Knapik, et al., 2004). Both cross-sectional (Reynolds, White, Knapik, Witt & Amoroso, 1999) and longitudinal (Orr, et al., 2015; Orr, Coyle, Johnston & Pope, 2017) studies have shown that different load distribution may have even larger negative effects and can increase the level of asymmetry. Studies conducted during quiet standing have concluded that loads with a predominant mass of >40% of body weight increase pressure velocity and the contact area between the foot and the ground, directly affecting ground reaction forces beneath different foot regions (Kasović, et al., 2022; Richmond, et al., 2021; Schiffman, et al., 2006; Strube, et al., 2017; Tahmasebi, et al., 2015; Walsh & Low, 2021).

Although carrying heavy loads has been mainly observed in military personnel (Walsh & Low, 2021), studies have shown that other special populations, like police officers, may be more prone to biomechanical foot changes during quiet stance (Kasović, et al., 2022). Intervention police officers are required to perform their everyday tasks at a maximal level (Zwingmann, Zedler, Kurzner, Wahl & Goldmann, 2021). Their primary role includes intervening against crime and they are engaged in high-risk situations that often exceed the capabilities of general police (Zwingmann, et al., 2021). The most common everyday tasks are related to personal or community protection of high risk, including sports matches and events, rural operations of controlling an illegal border crossing by immigrants, or even participating in counterterrorism operations (Irving, Orr & Pope , 2019). To be able to perform at high level, intervention police officers often need to carry external loads that exceed recommended levels of 45% of body mass (Department of the Army, 2017). Since intervention police officers may carry even heavier load than military personnel and engage in more high-risk situations (Zwingmann, et al., 2021), it is necessary to examine changes in biomechanical foot parameters during quiet standing under heavy load conditions.

Therefore, the main purpose of the study was to examine whether carrying progressively heavier loads ('no load', 'a 5 kg load', 'a 25 kg load', and 'a 45 kg load') had effects on postural sway and relative ground reaction forces during quiet stance in intervention police officers. We hypothesized that officers would exhibit greater biomechanical foot changes and impaired balance under heavier loads compared to the 'no load' condition.

## Methods

### Study participants

In this cross-sectional study, male officers of the Police Intervention Unit of the Zagreb Police Department were recruited. Out of 280 registered intervention police officers, we were able to recruit just 96 of them due to different field-based and administrative tasks other individuals were participating in. G*Power statistical calculator was used to calculate the effect size using partial eta squared and the one-way repeated-measures ANOVA to compare the effects of load configuration, with a p-value of <.05, achieved power of 0.80, a total recruited sample size of N = 80 (out of 280 participants), four measurements, correlation among repeated measures to be set at $r = 0.50$, and a nonsphericity correction index of 1, the achieved effect size with the aforementioned number of participants was f = 0.25. Considering the potential dispersion of the sample during the study, the initial sample size of 80 participants was increased by 20%, leading to the final sample of 96 participants. All participants in the research were employees of the Zagreb Police Intervention Unit for at least three years. All participants recruited for this study were men. Sociodemographic characteristics included age (mean ± SD; 38.2 ± 10.4 years), body height (179.2 ± 12.4 cm), body mass (86.4 ± 11.3 kg), body mass index (26.9 ± 3.8 kg/m$^2$), and waist circumference (93.5 ± 12.6 cm). The mean age of serving as an intervention police officer was 10.3 ± 3.3 years. Out of 96 participants, seven were underweight (7.3%), 65 had normal weight (67.7%), 20 were overweight (20.8%), and four were obese (4.2%). All participants signed a written informed consent to participate and stated that they did not have any acute/chronic diseases or injuries that would affect the test results or force them to drop-out from the study. The research was conducted anonymously and in accordance with the Helsinki Declaration (World Medical Association, 2013). This study was approved by the Ethical Committee of the Faculty of Kinesiology and the Police Intervention Department under the Ministry of Internal Affairs of the Republic of Croatia (Ethical code: 511-01-128-23-1).

### Loading conditions

During testing, each participant walked over a platform and carried four types of loads proposed by the Ministry of Internal Affairs for intervention police officers: (1) body weight only ('no load'), (2) a 5-kg load ('load 1', a belt with a pistol loaded with a full handgun's magazine, an additional full handgun's magazine and handcuffs), (3) a 25-kg load ('load 2'; 'load 1' upgraded by a helmet, a ballistic vest and a multipurpose baton), and (4) a 45-kg load ('load 3'; 'load 2' upgraded by the additional protection for the lower extremities and a protective gas mask). The order of the load carrying was randomized by the randomization software to reduce the impact of a learning effect (Kasović, et al., 2022). All the participants wore the same standardized equipment for each load condition. Of note, each participant wore the handgun on the dominant side of the body, which was predominantly the right side (93% of all the participants).

### Static foot parameters

Measurements were conducted at the same time in the evening hours and at the same place. All respondents were familiar with the measurement protocol before the measurements. First, the anthropometric characteristics of the examinees were measured, including body height and body mass. Ground reaction forces (absolute in N and relative in %) were measured. Each participant stepped barefoot on the Zebris medical platform for the measuring of pedobarographic plantar characteristics (type FDM 1.5). The Zebris platform uses 11.264 micro sensors, arranged across the walking area, with a frequency of 300 Hz. It has been used as a diagnostic device for supporting several modes of operation, including static analysis while a participant is standing quietly (Gregory & Robertson, 2017). The Zebris platform was connected via USB cable to an external unit (laptop). The data were gathered in real time using WinFDM software for the extraction and calculation. Measurement values could be additionally exported in the form of text, picture, and video, while simultaneously comparing the data from both feet. The capacity sensor technology was based on the automatic calibration of every single sensor integrated into the platform. The task was to stand on the platform and maintain a calm position, with the arms relaxed close to the body and looking straight forward. After 15 seconds of measurement, the following parameters were generated: (i) 95% confidence ellipse area ($mm^2$), (ii) CoP path length (mm), (iii) CoP average velocity (mm/s), (iv) length of the minor axis, (v) length of the major axis (mm), (vi) deviation X, (vii) deviation Y, and (viii) the angle between Y and the major axis (°). For ground reaction forces, the software generated the data for the relative forces distributed under the forefoot and hindfoot regions of the foot, as well as for the total foot (%). Of note, the vertical component of the ground reaction forces was collected and analyzed as well.

### Statistical analysis

Basic descriptive statistics are presented as mean and standard deviation (SD). The Kolmogorov-Smirnov test was used to assess the normality of the distribution. Pearson correlation coefficient was used to assess the level of connection between sociodemographic characteristics and changes under each load condition, to omit a potential mediation. One-way repeated-measures ANOVA was used to test the effects of load configuration ('no load', 'load 1', 'load 2' and 'load 3'). Where significant differences between load configurations were observed, a modified Bonferroni procedure was used. All statistical analyses were performed using SPSS v23.0 software (IBM, Armonk, NY, USA) with an alpha level set *a priori* at $p<.05$ to denote statistical significance.

## Results

Of note, sociodemographic characteristics of the study participants were not significantly correlated to changes in stance characteristics following different load conditions ($r = 0.03 – 0.21$, $p>.05$), omitting potential mediation between a specific load condition and spatiotemporal stance changes.

Changes in static foot parameters under the different loading conditions are presented in Table 1. Significant main effects were observed for confidence ellipse area, center of pressure path length and average velocity, length of the minor and major axes and deviation X. A Bonferroni *post-hoc* analyses revealed significant differences between 'no load' and 'load 3'. Specifically, carrying 'load 3' produced significantly larger effects on the aforementioned static foot parameters compared to the 'no load' condition. Interestingly, when carrying 'load 1', the value in deviation X axis significantly decreased compared to the 'no load' condition. Insignificant main effects in other static foot

*Table 1. Basic descriptive statistics and changes in static foot parameters under the different loading conditions in intervention police officers*

| Study variables | 'No load' | 'Load 1' | 'Load 2' | 'Load 3' | Main effect | |
|---|---|---|---|---|---|---|
| **Static parameters** | **Median (25th-75th)** | **Median (25th-75th)** | **Median (25th-75th)** | **Median (25th-75th)** | ***F* (p-value)** | **η2** |
| **Confidence ellipse area (mm²)** | 107.5 (68-183.5)[c] | 124.5 (77.5-253.8) | 144.5 (98.3-215.8) | 188.5 (98.8-297.5) | **3.672 (0.012)** | **0.028** |
| **Center of pressure path length (mm)** | 76.0 (63.3-91.8)[c] | 81.5 (63.0-107.8) | 82.0 (70.0-101.0) | 91.0 (71.3-114.5) | **3.801 (0.010)** | **0.029** |
| **Center of pressure average velocity (mm/s)** | 8.0 (6.0-9.0)[c] | 8.0 (6.0-11.0) | 8.0 (7.0-11.0) | 9.0 (7.0-11.0) | **3.778 (0.011)** | **0.029** |
| **Length of the minor axis (mm)** | 7.4 (5.1-9.6)[a,c] | 8.3 (6.2-12.2) | 8.6 (6.3-11.3) | 9.1 (7.2-12.1) | **5.259 (<0.001)** | **0.040** |
| **Length of the major axis (mm)** | 18.6 (14.8-24.5)[c] | 22.1 (16.1-27.7) | 21.1 (17.6-27.0) | 23.9 (18.8-32.3) | **4.550 (0.004)** | **0.035** |
| **Angle btween Y and the major axis (°)*** | 75.0 (16.0) | 75.7 (14.5) | 74.9 (15.4) | 72.1 (20.0) | 0.868 (0.458) | 0.007 |
| **Deviation X (mm)** | 18.9 (8.4-31.0)[a] | 13.9 (3.8-23.5) | 17.7 (9.5-27.3) | 18.4 (8.8-27.6) | **2.698 (0.046)** | **0.021** |
| **Deviation Y (mm)** | 4.8 (-4.0-10.4) | 6.9 (-2.2-15.2) | 9.1 (-0.7-19.4) | 9.3 (-2.2-17.1) | 0.141 (0.935) | 0.001 |
| **Relative average force-left forefoot (%)** | 54.1 (5.7) | 55.0 (6.6) | 55.5 (6.8) | 55.5 (8.3) | 0.884 (0.449) | 0.007 |
| **Relative average force-left hindfoot (%)** | 45.9 (5.7) | 45.1 (6.6) | 44.5 (6.8) | 44.5 (8.3) | 0.898 (0.442) | 0.007 |
| **Relative average force-left total (%)** | 44.9 (9.6) | 46.3 (9.1) | 44.1 (8.6) | 44.3 (7.3) | 1.233 (0.297) | 0.010 |
| **Relative average force-right forefoot (%)** | 51.2 (7.9) | 51.4 (10.1) | 50.8 (8.7) | 51.0 (7.7) | 0.079 (0.972) | 0.001 |
| **Relative average force-right hindfoot (%)** | 48.8 (7.9) | 48.0 (8.7) | 49.2 (8.7) | 49.0 (7.7) | 0.354 (0.787) | 0.003 |
| **Relative average force-right total (%)** | 55.2 (9.6) | 53.7 (9.1) | 56.0 (8.4) | 55.7 (7.3) | 1.318 (0.268) | 0.010 |

Note. [a] denotes significant differences between 'no load' and 'load 1'; [b] denotes significant differences between 'no load' and 'load 2'; [c] denotes significant differences between 'no load' and 'load 3'; [d] denotes significant differences between 'load 1' and 'load 2'; [e] denotes significant differences between 'load 1' and 'load 3'; [f] denotes significant differences between 'load 2' and 'load 3'. p<.05.

parameters were observed, pointing out that heavier equipment did not significantly impact deviation Y and relative forces under forefoot and hindfoot regions of both feet (p>.05).

## Discussion and conclusions

The main purpose of the study was to examine whether heavier equipment led to changes in postural sway and relative ground reaction forces during quiet stance in intervention police officers. The main findings of the study are: (i) with the increased mass, increases in the center of pressure path length, average velocity and lengths of the minor and major axes gradually increased, and (ii) no significant changes in relative ground reaction forces beneath the forefoot and hindfoot regions of the foot were observed irrespective of heavier loads. Based on the aforementioned findings, the hypothesis of spatiotemporal and kinetic static foot changes when carrying different load could be partially confirmed, where spatiotemporal parameters led to significant changes, while relative ground reaction forces remained unchanged.

To the best of authors' knowledge, this is one of the first studies that examined whether heavier loads might impact static foot parameters in intervention police officers. Previous evidence has confirmed that heavier loads may impact several foot characteristics during quiet stance, including increases in mean postural sway during a double stance, the center of pressure path length, average velocity and lengths of the minor and major axes with a decrease in the angle between Y and the major axis (Strube et al., 2017; Walsh & Low, 2021). Specifically, a study by Strube et al. (2017) showed that mean postural sway velocity during a double leg stance increased from 0.27°·s$^{-1}$ to 0.34°·s$^{-1}$ when carrying 'a 16.0-kg load' and to 0.52°·s$^{-1}$ under the '20.5-kg load', indicating a linear velocity increase while carrying heavier loads. However, the pattern of our findings clearly indicated significant differences only between 'no load' and 'load 1'/'load 3', while no other differences were observed. Unfortunately, we performed the experiment with a relatively small sample of intervention police officers; a greater sample might have led to a greater heterogeneity between the study participants in terms of their different characteristics, the duration of the load application, or the sensitivity of the postural sway measurement techniques employed. The nature of Zebris platform applied in this study was focused on vertical component (axis) of collecting the data, while antero-posterior or medio-lateral directions could not be determined. Although limited data had a significant impact on generalizability of the findings, uneven effects of carrying heavier loads on postural sway may be explained by the fact that experienced intervention police officers participated in the study, whose body adaptations were more adequate compared to new recruits. This is in line with previous evidence, where heavy load carried by young adults led to a decrease in postural stability with significant effects on the center of pressure sway area and the center of pressure anterior-posterior excursion (Martin, et al., 2023). Interestingly, studies have shown that 'a 16-kg load' may represent a significant cut-off point and result in substantial alterations in postural control (Heller, et al., 2009; Schiffman, et al., 2006; Strube, et al., 2017), compared to lighter loads, which is not in line with our findings. The *post-hoc* analysis showed that compared to the 'no load', 'a 45-kg load' led to significant changes in postural sway, mainly in the center of pressure. Of many potential factors influencing body posture, muscle activation plays an important role in maintaining an upright body posture and controls the integration of sensory systems during quiet standing (Kodithuwakku Arachchige, et al., 2020). Also, load placement relative to the body's center of mass was found to influence the amount of postural sway (Rugelj & Sevšek, 2011); when the load was placed above the center of mass, the sway parameters increased (Qu & Nussbaum, 2009). Although we were unable to test different load distribution and its impact on foot characteristics during quiet standing, studies have shown that load re-distribution towards the hips is an essential part of reducing metabolic costs and increasing contributions of hip muscles to forward progression (Jones, Canham-Chervak, Canada, Mitchener & Moore, 2010; Kavounoudias, Gilhodes, Roll & Roll, 1999). Heavier loads lead to greater foot changes and body sway during standing, which directly disrupt the body's center of mass to shift from a stable to the boundaries of the base of support, expecting a loss of balance in medio-lateral and anterior-posterior directions essential to maintain an upright stance by using the ankle and the hip compensation movements (Schiffman, et al., 2006). Losing postural stability is based on a stable system of a kinetic chain between gravity, the base of support and the center of mass. When an upright neutral position is impacted by external load, the resulting body motion is counterbalanced by one of the strategies which increases postural sway. Beside biomechanical, the physiological effects of carrying heavy loads often result in larger heart rate frequency, respiratory changes and proprioceptive systems (Horak & Nashner, 1986).

Along with postural changes, we observed no effects of carrying load on relative ground reaction forces, which is not in line with previous findings (Birrell, Hooper & Haslam, 2007; Kasović, et al., 2022; Walsh & Low, 2021). A study by Walsh and Low (2021) concluded that ground reaction forces linearly increased with heavier load. On the other hand, observing no changes in ground reaction forces was shown in a study by Goffar et al. (2013). The discrepancy in the findings may be due to different measuring modes and techniques, where the majority of the studies have been conducted in dynamic conditions, while we based the findings in static conditions. Again, more experienced officers may better compensate for heavy load, and since the load was placed near the body in this study, it is speculated that load placement away from the body may have produced different changes in ground reaction forces. Also, the software used to generate the data on calculated ground reaction forces relative to body weight, which is one of the novelties of this study. Although a quarter of the participants were overweight or obese, the interaction between body mass index and changes in postural sway or ground reaction forces were non-significant, meaning that both absolute and relative values of body mass index in our sample were homogenous and other risk factors should be taken into account when establishing the effect of load carriage on static foot parameters.

In general, carrying heavy loads is an essential part of special populations' tasks. Along with its benefits, a negative trend of an increase in heavy loads lead to a certain delay in the feedback of the ability to maintain an upright control and posture. However, body movement patterns away from equilibrium often require compensations towards the initial position, steadily increasing the structure of the postural sway movements (Schiffman, et al., 2006). Indeed, heavy loads increase injury incidence and lower physical performance (Wills, et al., 2021), and by using a biomechanical approach, health-related professionals and companies which design police equipment may adequately develop policies which can help in creating and positioning ergonomically appropriate equipment on the body without large negative biomechanical effects or deviations.

This study has several limitations. First, by using a cross-sectional design, we were unable to examine longitudinal changes in static foot parameters while carrying heavy loads. Second, a relatively small sample size (N = 96) may have led to insufficient statistical power. However, at the time of the study had been conducted and eligible number of participants, the sample size seemed appropriate to detect large effects between load conditions. Next, we did not collect biological and physiological parameters, which may interrogate between static foot parameters and different loading conditions. Also, no collection of data regarding injury history or how load was carried was not collected, limiting the possibility to expand our findings to practical implications towards re-positioning items and exploring potential effects of load carriage on the incidence of injuries. Finally, no 3D kinematic and muscle activation systems were assessed, limiting our findings to be observed only through a pressure platform and vertical projection of ground reaction forces. Finally, participants walked barefoot over the pressure platform, potentially limiting the generalizability and applicability of the findings to different everyday tasks of other populations of police-related field or military personnel (Lenton, et al., 2019). Based on the aforementioned limitations, future longitudinal studies conducted among larger sample sizes, adjusted for potential mediators and measured with sophisticated kinematic, kinetic and electromyography systems, should be performed, in order to establish biomechanical changes and proper re-distribution load properties for minimizing injury risk.

In summary, this is one of the first studies examining changes in static foot parameters under different loading conditions. The findings of the study showed that with gradually increased external loads, the center of pressure path length and velocity increased along with the major and minor axes, while changes in ground reaction forces beneath the different foot regions were not impacted by the load. Therefore, spatial and temporal parameters during quiet standing may be more prone to changes following heavy loads compared to ground reaction forces, pointing out that future research should focus on foot characteristics, rather than forces being generated beneath the feet.

## References

Andersen, K.A., Grimshaw, P.N., Kelso, R.M., & Bentley, D.J. (2016). Musculoskeletal lower limb injury risk in army populations. *Sports Medicine—Open*, *2*, 22. https://doi.org/10.1186/s40798-016-0046-z

Birrell, S.A., Hooper, R.H., & Haslam, R.A. (2007). The effect of military load carriage on ground reaction forces. *Gait and Posture*, *26*(4), 611-614. https://doi.org/10.1016/j.gaitpost.2006.12.008

Blacker, S.D., Fallowfield, J.L., Bilzon, J.L., & Willems, M.E. (2010). Neuromuscular function following prolonged load carriage on level and downhill gradients. *Aviation, Space, and Environmental Medicine*, *81*(8), 745-753. https://doi.org/10.3357/asem.2659.2010

Boffey, D., Harat, I., Gepner, Y., Frosti, C.L., Funk, S., & Hoffman, J.R. (2019). The physiology and biomechanics of load carriage performance. *Military Medicine*, *184*(1-2), e83-e90. https://doi.org/10.1093/milmed/usy218

Brushøj, C., Larsen, K., Albrecht-Beste, E., Nielsen, M.B., Løye, F., & Hölmich, P. (2008). Prevention of overuse injuries by a concurrent exercise program in subjects exposed to an increase in training load: A randomized controlled trial of 1020 army recruits. *The American Journal of Sports Medicine*, *36*(4), 663-670. https://doi.org/10.1177/0363546508315469

Department of the Army (US Foot Marches; Department of the Army (US): Washington, DC, USA, 2017.

Fallowfield, J.L., Blacker, S.D., Willems, M.E., Davey, T., & Layden, J. (2012). Neuromuscular and cardiovascular responses of Royal Marine recruits to load carriage in the field. *Applied Ergonomics*, *43*(6), 1131-1137. https://doi.org/10.1016/j.apergo.2012.04.003

Fox, B.D., Judge, L.W., Dickin, D.C., & Wang, H. (2020). Biomechanics of military load carriage and resulting musculoskeletal injury: A review. *Journal of Orthopedics and Orthopedic Surgery*, *1*(1), 6-11.

Goffar, S. L., Reber, R. J., Christiansen, B. C., Miller, R. B., Naylor, J. A., Rodriguez, B. M., Walker, M. J., & Teyhen, D. S. (2013). Changes in dynamic plantar pressure during loaded gait. *Physical therapy*, *93*(9), 1175–1184. https://doi.org/10.2522/ptj.20120103

Gregory, R.W., & Robertson, M.I. (2017). The validity of the Zebris FDM system for measuring static balance. *Medicine and Science in Sport and Exercise*, *49*, 683.

Heller, M.F., Challis, J.H., & Sharkey, N.A. (2009). Changes in postural sway as a consequence of wearing a military backpack. *Gait and Posture*, *30*(1), 115-117. https://doi.org/10.1016/j.gaitpost.2009.02.015

Horak, F.B., & Nashner, L.M. (1986). Central programming of postural movements: Adaptation to altered support-surface configurations. *Journal of Neurophysiology*, *55*(6), 1369-1381. https://doi.org/10.1152/jn.1986.55.6.1369

Irving, S., Orr, R., & Pope, R. (2019). Profiling the occupational tasks and physical conditioning of specialist police. *International Journal of Exercise Science*, *12*(3), 173-186.

Jones, B.H., Canham-Chervak, M., Canada, S., Mitchener, T.A., & Moore, S. (2010). Medical surveillance of injuries in the U.S. Military: Descriptive epidemiology and recommendations for improvement. *American Journal of Preventive Medicine*, *38*(1 Suppl), S42-S60. https://doi.org/10.1016/j.amepre.2009.10.014

Kasović, M., Vespalec, T., & Štefan, L. (2022). Effects of load carriage on postural sway and relative ground reaction forces in special police officers: A cross-sectional study. *International Journal of Environmental Research and Public Health*, *19*(24), 16710. https://doi.org/10.3390/ijerph192416710

Kavounoudias, A., Gilhodes, J.C., Roll, R., & Roll, J.P. (1999). From balance regulation to body orientation: Two goals for muscle proprioceptive information processing?. *Experimental Brain Research*, *124*(1), 80-88. https://doi.org/10.1007/s002210050602

Knapik, J.J., Reynolds, K.L., & Harman, E. (2004). Soldier load carriage: Historical, physiological, biomechanical, and medical aspects. *Military Medicine*, *169*(1), 45-56. https://doi.org/10.7205/milmed.169.1.45

Kodithuwakku Arachchige, S.N., Chander, H., Turner, A.J., Wilson, S.J., Simpson, J.D., Knight, A.C., ..., & Carruth, D. (2020). Muscle activity during postural stability tasks: Role of military footwear and load carriage. *Safety*, *6*(3), 35. https://doi.org/10.3390/safety6030035

Kroemer, K.H., & Grandjean, E. (1997). *Fitting the task to the human: A textbook of occupational ergonomics* (5th ed.). Abingdon, UK: Taylor & Francis.

Lenton, G.K., Doyle, T.L.A., Lloyd, D.G., Higgs, J., Billing, D., & Saxby, D.J. (2019). Lower-limb joint work and power are modulated during load carriage based on load configuration and walking speed. *Journal of Biomechanics*, *83*, 174-180. https://doi.org/10.1016/j.jbiomech.2018.11.036

Martin, J., Kearney, J., Nestrowitz, S., Burke, A., & Sax van der Weyden, M. (2023). Effects of load carriage on measures of postural sway in healthy, young adults: A systematic review and meta-analysis. *Applied Ergonomics*, *106*, 103893. https://doi.org/10.1016/j.apergo.2022.103893

Orr, R.M., Coyle, J., Johnston, V., & Pope, R. (2017). Self-reported load carriage injuries of military soldiers. *International Journal of Injury Control and Safety Promotion*, *24*(2), 189-197. https://doi.org/10.1080/17457300.2015.1132731

Orr, R.M., Johnston, V., Coyle, J., & Pope, R. (2015). Reported load carriage injuries of the Australian army soldier. *Journal of Occupational Rehabilitation*, *25*(2), 316-322. https://doi.org/10.1007/s10926-014-9540-7

Orr, R., Hinton, B., Wilson, A., Pope, R., & Dawes, J. (2020). Investigating the routine dispatch tasks performed by police officers. *Safety, 6*(4), 54. https://doi.org/10.3390/safety6040054

Pollock, A.S., Durward, B.R., Rowe, P.J., & Paul, J.P. (2000). What is balance?. *Clinical Rehabilitation*, *14*(4), 402-406. https://doi.org/10.1191/0269215500cr342oa

Qu, X., & Nussbaum, M.A. (2009). Effects of external loads on balance control during upright stance: Experimental results and model-based predictions. *Gait and Posture*, *29*(1), 23-30. https://doi.org/10.1016/j.gaitpost.2008.05.014

Reynolds, K.L., White, J.S., Knapik, J.J., Witt, C.E., & Amoroso, P.J. (1999). Injuries and risk factors in a 100-mile (161-km) infantry road march. *Preventive Medicine*, *28*(2), 167-173. https://doi.org/10.1006/pmed.1998.0396

Richmond, S.B., Fling, B.W., Lee, H., & Peterson, D.S. (2021). The assessment of center of mass and center of pressure during quiet stance: Current applications and future directions. *Journal of Biomechanics*, *123*, 110485. https://doi.org/10.1016/j.jbiomech.2021.110485

Rugelj, D., & Sevšek, F. (2011). The effect of load mass and its placement on postural sway. *Applied Ergonomics*, *42*(6), 860-866. https://doi.org/10.1016/j.apergo.2011.02.002

Schiffman, J.M., Bensel, C.K., Hasselquist, L., Gregorczyk, K.N., & Piscitelle, L. (2006). Effects of carried weight on random motion and traditional measures of postural sway. *Applied Ergonomics*, *37*(5), 607-614. https://doi.org/10.1016/j.apergo.2005.10.002

Strube, E.M., Sumner, A., Kollock, R., Games, K.E., Lackamp, M.A., Mizutani, M., & Sefton, J.M. (2017). The effect of military load carriage on postural sway, forward trunk lean, and pelvic girdle motion. *International Journal of Exercise Science*, *10*(1), 25-36.

Tahmasebi, R., Karimi, M.T., Satvati, B., & Fatoye, F. (2015). Evaluation of standing stability in individuals with flatfeet. *Foot and Ankle Specialist*, *8*(3), 168-174. https://doi.org/10.1177/1938640014557075

Walsh, G.S., & Low, D.C. (2021). Military load carriage effects on the gait of military personnel: A systematic review. *Applied Ergonomics*, *93*, 103376. https://doi.org/10.1016/j.apergo.2021.103376

Wills, J.A., Saxby, D.J., Lenton, G.K., & Doyle, T.L.A. (2021). Lower limb biomechanical responses during a standardized load carriage task are sex specific. *Military Medicine*, *186*(11-12), 1157-1168. https://doi.org/10.1093/milmed/usab093

World Medical Association. (2013). World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects. *JAMA*, *310*(20), 2191-2194. https://doi.org/10.1001/jama.2013.281053

Zultowski, I., & Aruin, A. (2008). Carrying loads and postural sway in standing: The effect of load placement and magnitude. *Work (Reading, Mass)*, *30*(4), 359-368.

Zwingmann, L., Zedler, M., Kurzner, S., Wahl, P., & Goldmann, J.P. (2021). How fit are special operations police officers? A comparison with elite athletes from Olympic disciplines. *Frontiers in Sports and Active Living*, *3*, 742655. https://doi.org/10.3389/fspor.2021.742655

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